APPENDIX D. METEOROLOGICAL CONDITIONS.

D.1 Meteorological Conditions

D.1.1 Icing Cloud Specifications

The cloud parameters and their ranges of values that are required for the design and approval of aircraft inflight ice protection equipment are provided in 14 CFR parts 25 and 29 Appendix C [D1]. The icing envelopes may be reduced because of the aircraft's flight envelope limitations. The Appendix C envelopes were first introduced by Amendment 4b-2 to CAR 4b during August 25, 1955. The charts were derived from tabulations presented in [D2]. One of the principal investigators has stated that the icing conditions shown in Appendix C do not present physical relations among the variables [D3]. Instead, they represent combinations of the three variables (LWC, drop size, and temperature) believed to have a sufficient frequency of occurrence to warrant consideration in design.

Drop diameter was found to be only weakly correlated with either water content or temperature. Investigation of data contained in [D1] began with the development of wing heated anti-icing systems. Most of the flight measurements of liquid water content and effective drop diameter were made by means of the rotating-cylinder technique. Theoretical relations involving drop diameter, cylinder diameter, collection efficiency, and airspeed were used to derive average liquid water content and effective drop diameter. The method also yielded a rough measure of the spread in the size distribution. More dependable information on the distribution could have been obtained from actual counts of drops capture in oil, but few such determinations were made.

The selection of the design conditions required consideration of the tolerance of the heated anti-icing system to temporary overloading, and especially the ability to recover after short periods in extreme conditions. The continuous maximum and intermittent maximum conditions contained in Appendix C were considered envelopes of maximum-severity conditions applicable to stratiform and cumulus clouds during winter. Selection of the design conditions for each category of icing conditions was based on the concept that the anti-icing system should provide full protection in roughly 99 percent of icing encounters and that slight, temporary impairment of performance could be accepted. It was realized that on rare occasions icing of exceptional severity might require evasive action.

Figures D-1 through D-6 reproduce figures 1 through 6 of 14 CFR parts 25 and 29 Appendix C. Figures D-1 and D-4 (Figures 1 and 4 of 14 CFR parts 25 and 29 Appendix C) estimate the "probable maximum" (99^{th} percentile) value of cloud water concentration (commonly known as LWC) that is to be expected, as an average over a specified reference distance, for a given temperature and droplet size [D4]. In defining the envelope of combination of LWC, MED, and T, the investigators of [D5] determined that the condition that 99 percent of cases lie within the envelopes was roughly equivalent to a probability of 1/1000 that all three variables represented by a single point would be exceeded simultaneously. For Figure D-1 (Figure 1 of 14 CFR parts 25 and 29 Appendix C) this reference distance is 20 statute miles (17.4 nmi) in stratiform icing conditions, and for Figure D-4 (Figure 4 of 14 CFR parts 25 and 29 Appendix C) it is 3 statute miles (2.6 nmi) in convective icing conditions. These are arbitrary reference distances but are based on the original NACA research flights in the late 1940s. These probable maximum values of LWC were estimated by the NACA and Weather Bureau researchers in the early 1950s, when they first proposed them as the basis for the present-day 14 CFR parts 25 and 29 Appendix C [D2, D5]. Review of recently obtained icing cloud characterization information with modern instrumentation has shown that the 1940 data used to derive 14 CFR parts 25 and 29 Appendix C, were acceptably accurate.

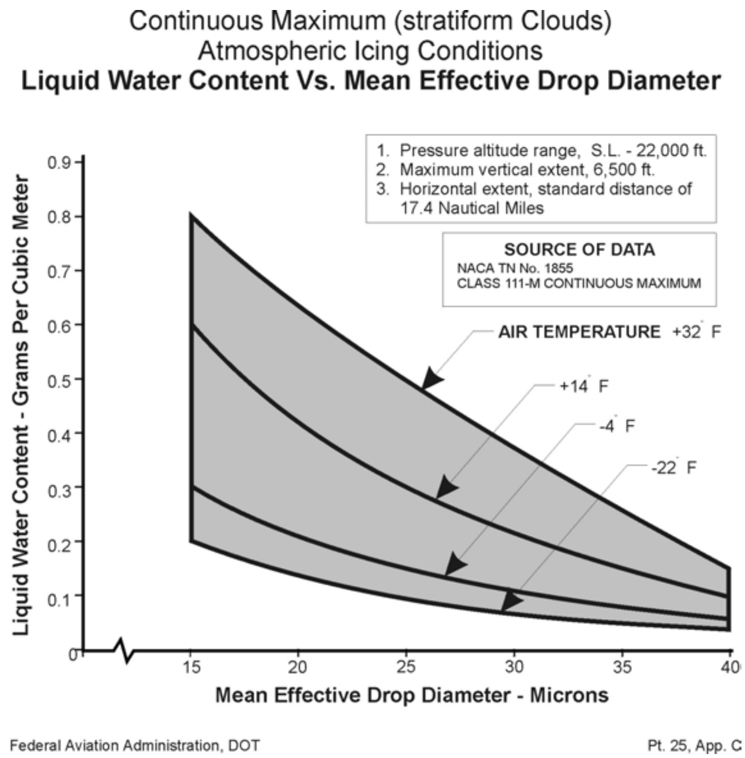


Figure D-1. **14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs. Mean Effective Drop Diameter (Figure 1, 14 CFR parts 25 and 29 Appendix C).**

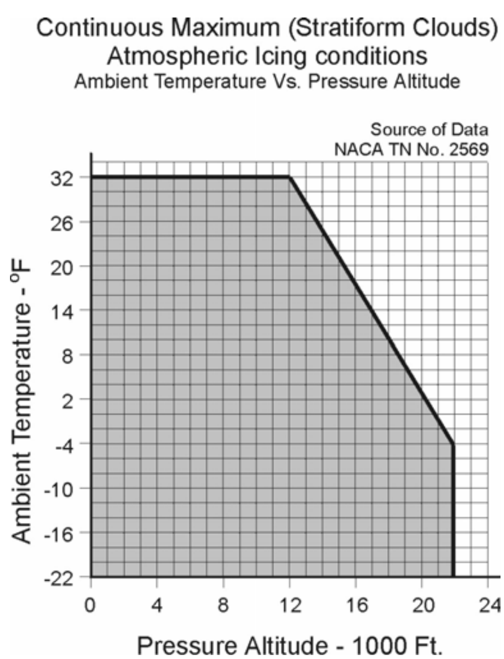


Figure D-2. **14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Ambient Temperature Vs. Pressure Altitude (Figure 2, 14 CFR parts 25 and 29 Appendix C).**

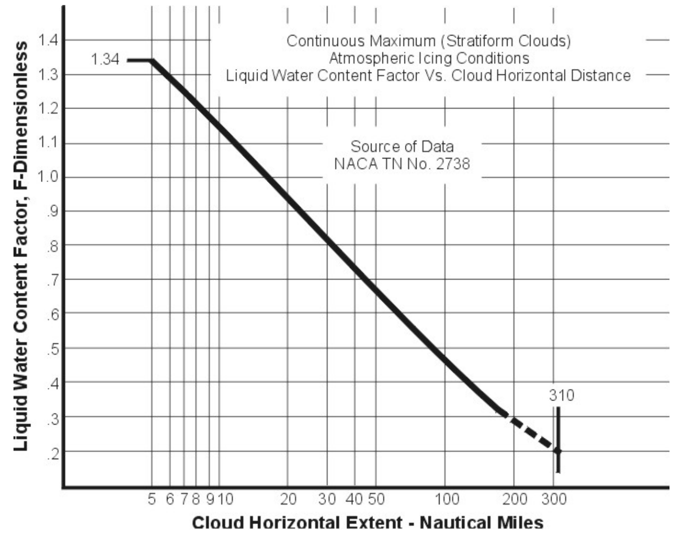


Figure D-3. **14 CFR Parts 25 and 29 Appendix C Continuous Maximum (Stratiform Clouds) Atmospheric Icing Conditions, Liquid Water Content Factor Vs. Cloud Horizontal Distance (Figure 3, 14 CFR parts 25 and 29 Appendix C).**

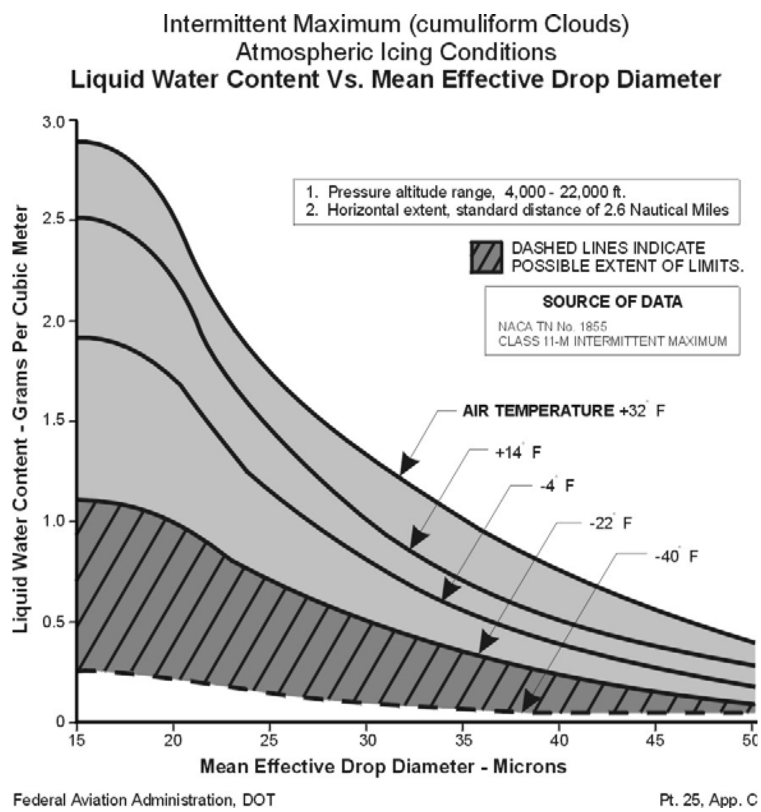


Figure D-4. **14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulous Clouds) Atmospheric Icing Conditions, Liquid Water Content Vs. Mean Effective Drop Diameter (Figure 4, 14 CFR parts 25 and 29 Appendix C).**

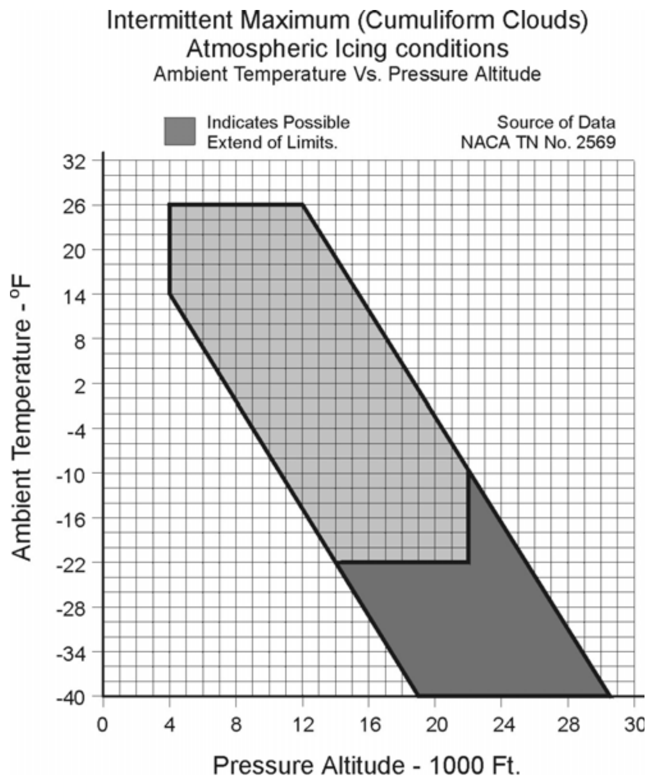


Figure D-5. **14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulous Clouds) Atmospheric Icing, Ambient Temperature Vs. Pressure Altitude (Figure 5, 14 CFR parts 25 and 29 Appendix C).**

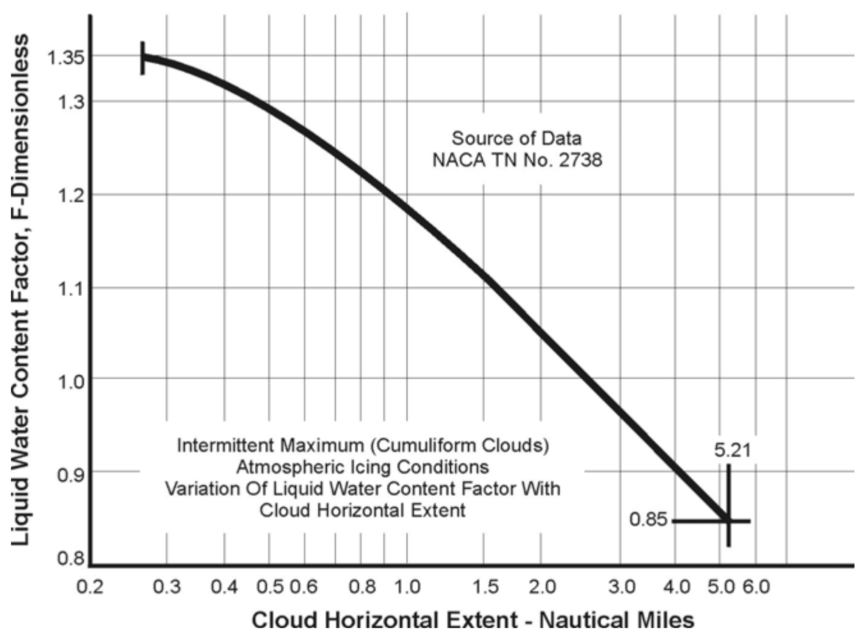


Figure D-6. **14 CFR Parts 25 and 29 Appendix C Intermittent Maximum (Cumulous Clouds) Atmospheric Icing Conditions, Liquid Water Content Factor Vs. Cloud Horizontal Distance (Figure 6, 14 CFR parts 25 and 29 Appendix C)**

The extension of the Intermittent Maximum envelopes below –22 °F (-30 °C) was done "for completeness" in the original data source [D2], but the exact values of LWC were regarded as uncertain due to the lack of data at these low temperatures. Nevertheless, the fact that these extensions appear in the regulations [D1] means that they must be considered as a design requirement.

In these icing applications, the actual droplet size distribution (typically 10-30 µm diameter) in clouds is represented by a single variable called the droplet median volume diameter (MVD) or, in the older usage, an approximately equivalent variable called the MED. The MVD is the midpoint of the LWC distribution over the range of cloud droplet sizes that happen to be present at the time. The MVD therefore varies with the number of droplets in each size category, but the overall average for layer clouds is about 15 µm and about 19 µm for convective clouds, based on data reviewed by the FAA. The MVD has proven useful as a simple substitute for the full droplet size distributions in ice accretion computations.

Icing conditions defined by 14 CFR part 29 Appendix C, may be truncated to a pressure altitude of 10,000 feet or the altitude limitation of the aircraft. AC 29-2C states that icing conditions envelopes contained in AC 29-2C may be selected by applicants who elect to certify rotorcraft with a 10,000 pressure altitude limit on the basis of equivalent safety. (For above 10,000 feet pressure altitude, AC 29-2C states that 14 CFR part 29 Appendix C icing conditions must be used.)

The AC 29-2C icing conditions envelopes resulted from an analysis (performed by the FAA W. J. Hughes Technical Center during 1985) of the data used to establish 14 CFR part 29 Appendix C, and are significantly different than those provided in 14 CFR part 29 Appendix C. For example, the AC 29-2C icing conditions envelopes for altitudes of 10,000 and lower indicate that temperatures colder than –10 °F and 0 °F need to be addressed for continuous and intermittent icing conditions, respectively. Comparative temperatures contained in 14 CFR part 29 Appendix C are –22 °F and –6 °F for continuous maximum and intermittent maximum icing conditions, respectively. Also, the AC 29-2C intermittent icing conditions minimum altitude is truncated at 4,000 feet, as compared to sea level for 14 CFR part 29 Appendix C intermittent maximum icing conditions. Since icing conditions requirements provided by AC 29-2C differ and are less stringent than that required by parts 27 and 29 § 1419, FAA Legal General Counsel should be consulted prior to allowing their use.

D.1.2 Using 14 CFR Parts 25 and 29 Appendix C

Although there is no comprehensive guide to the use, interpretation, and application of Appendix C, design engineers typically select a droplet MVD of interest and a temperature appropriate to the flight level of concern, and then use them to obtain the probable maximum LWC from Figure D-1 or D-4 (Figures 1 or 4 of 14 CFR parts 25 and 29 Appendix C). Other suggested or conventional practices are contained in this Advisory Circular and are scattered in other references [D6-D10].

Temperatures may be selected from the corners (extremes) of the temperature vs. altitude envelopes (Figures 2 and 5 of Appendix C, Figures D-2 and D-5 of this Advisory Circular) or from average or extreme values for the flight altitude under consideration. See [D9] for several example applications.

The values of LWC obtained directly from Figures D-1 or D-4 (Figure 1 or 4 of 14 CFR parts 25 and 29 Appendix C) are valid only for the reference distances of 17.4 nmi or 2.6 nmi, respectively. These were recommended by NACA researchers [D2] as "appropriate" design distances for ice protection considerations, and should be used for design of the IPS.

But if there is some reason to design for a longer (or shorter) exposure distance, then the LWC originally selected may be reduced (or increased) for some applications by a factor obtained from Figures D-3 (Figure 3 of 14 CFR parts 25 and 29 Appendix C) or D-6 (Figure 6 of 14 CFR parts 25 and 29 Appendix C). This is because for both types of clouds, longer averaging distances will result in lower maximum values of LWC as an average over the total exposure distance. To account for this behavior, adjustment factors (F-factors) (Figures 3 and 6 of 14 CFR parts 25 and 29 Appendix C and Figures D-3 and D-6 of this Advisory Circular) had to be developed so the envelopes could be adapted to other averaging distances.

The choice of exposure distance depends on the application at hand. One common application is to estimate ice buildup amounts on unprotected surfaces during a long exposure of perhaps 100 or 200 miles (see page 4.1-10, in [D9]). In this case, the LWC obtained from Figure D-1 is customarily reduced by an amount obtained from Figure D-3 for the selected exposure distance. For example, to find the maximum probable LWC expected during flight through 100 nmi of stratiform icing clouds, the appropriate multiplying factor (0.46 in this example) is taken from Figure D-3. Thus, for stratiform clouds in which the MVD is 15 µm and the temperature is -10 °C (+14 °F), the maximum average LWC over 100 nmi is expected to be 0.46 x 0.6 g/m^3 = 0.28 g/m^3. Basically, this procedure amounts to raising or lowering the LWC curves in Figures D-1 or D-4, depending on the exposure distance.

Another application is to estimate ice buildups on unprotected surfaces during a 45-minute hold situation (see also Section 8 of this advisory circular). For holding situations, the LWC obtained from Figure D-1 is used at full value without any reduction [D6], although AC 1419-2B offers that a droplet MVD of 22 µm and an LWC of 0.5 gm/m^3 with no horizontal extent correction is normally used for this analysis. In any case, it assumes the worst case in which the holding pattern happens to be entirely within a 17.4-nmi region of cloudiness containing a relatively large LWC.

Note that the adjustment of the LWC curves to obtain probable maximum values of LWC for other distances is the only valid use of the F-factor curves. Any other use of the F-factor curves is incorrect. Specifically, it is not valid to apply the F-factors to measured flight test LWCs to try to:

a) extrapolate available LWCs to values they supposedly would have if the exposures had been over the design distances of 17.4 nmi or 2.6 nmi instead of longer or shorter available distances,
b) compensate in flight for smaller-than-desired LWCs by extending the exposure distances by some calculable amount to achieve an exposure that is supposedly equivalent to the desired LWC over the design exposure distance,
c) devise some rating system for comparing available test exposures to design exposures.

Various schemes attempting to use the F-factor for applications like this have been invented by users in the past, but none of them appear to be entirely legitimate or satisfactory. Appendices N and O of this advisory circular provide acceptable ways of documenting variable length icing exposures without invoking the F-factor.

D.2 References

D1. Code of Federal Regulations, Title 14, Parts 1-59 (revised and re-issued annually); Office of the Federal Register, National Archives and Records Administration, Washington, DC 20408; (full text available at http://www.access.gpo.gov/nara).

D2. **"Recommended Values of Meteorological Factors to be Considered in the Design of Aircraft Ice-Prevention Equipment,"** NACA Technical Note 1855 (1949), NASA/Ames Research Center, Moffett Field, California 94035.

D3. "Review of Icing Criteria," Lewis, William, Aircraft Ice Protection, Report of Symposium, Engineering and Manufacturing Division, Flight Standards Service, Department of Transportation, Federal Aviation Administration, dated April 28-30, 1969.

D4. **"Review of Icing Criteria,"** Lewis, William, <u>Aircraft Ice Protection, Report of Symposium, April 28-30, 1969.</u>

D5. "**A Probability Analysis of the Meteorological Factors Conducive to Aircraft Icing in the United States,**" NACA Technical Note 2738 (1952), NASA/Lewis Research Center, Cleveland, OH 44135.

D6. "**Certification of Part 23 Airplanes for Flight in Icing Conditions,**" Advisory Circular 23.1419-2B (1998); Federal Aviation Administration, Washington, DC 20591.

D7. "**Certification of Transport Category Airplanes for Flight in Icing Conditions,**" Advisory Circular 25.1419-1 (1999); Federal Aviation Administration, Washington, DC 20591.

D8. "**Certification of Transport Category Rotorcraft,**" Advisory Circular 29-2C (1999); Federal Aviation Administration, Washington, DC 20591.

D9. "**Engineering Summary of Airframe Icing Technical Data,**" D.T. Bowden et al., Technical Report ADS-4 (1963); Federal Aviation Administration, Washington, DC 20591.

D10. "**Aircraft Icing Handbook,**" FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA Technical Center, Atlantic City, NJ 08405.

APPENDIX E. COMPONENT ICE PROTECTION SYSTEM DESIGN AND CERTIFICATION PROCESSES.

The process of a typical inflight icing certification program is illustrated in Figure E-1. Typical icing certification processes for various components of an aircraft's IPS are illustrated in Figures E-2 through E-7. These process diagrams are general in nature and may not be comprehensive for all inflight icing certification programs. Each aircraft model should be assessed for design features that warrant additional considerations relative to safe flight in icing conditions.

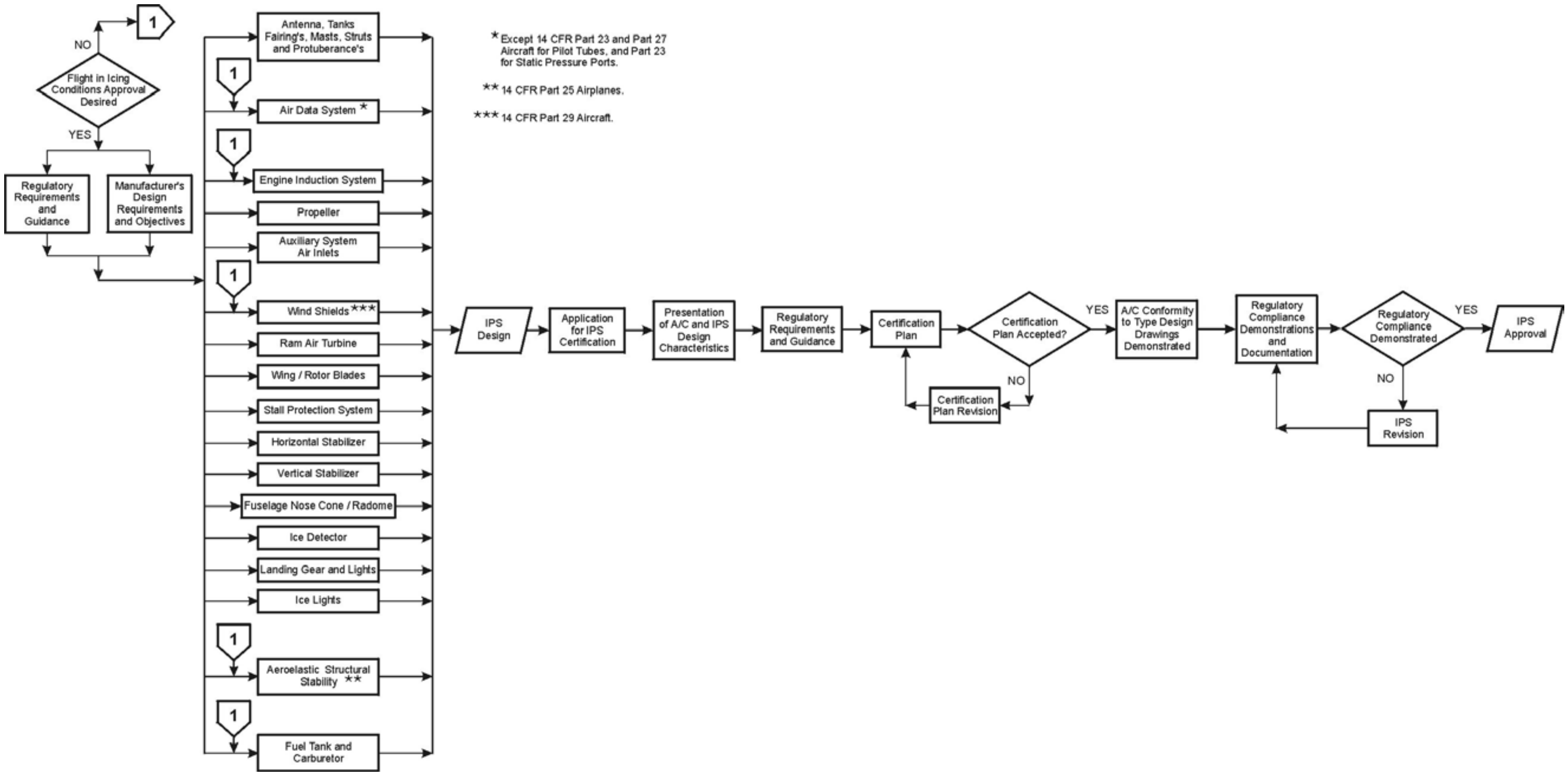


Figure E-1. Typical aircraft inflight icing certification process.

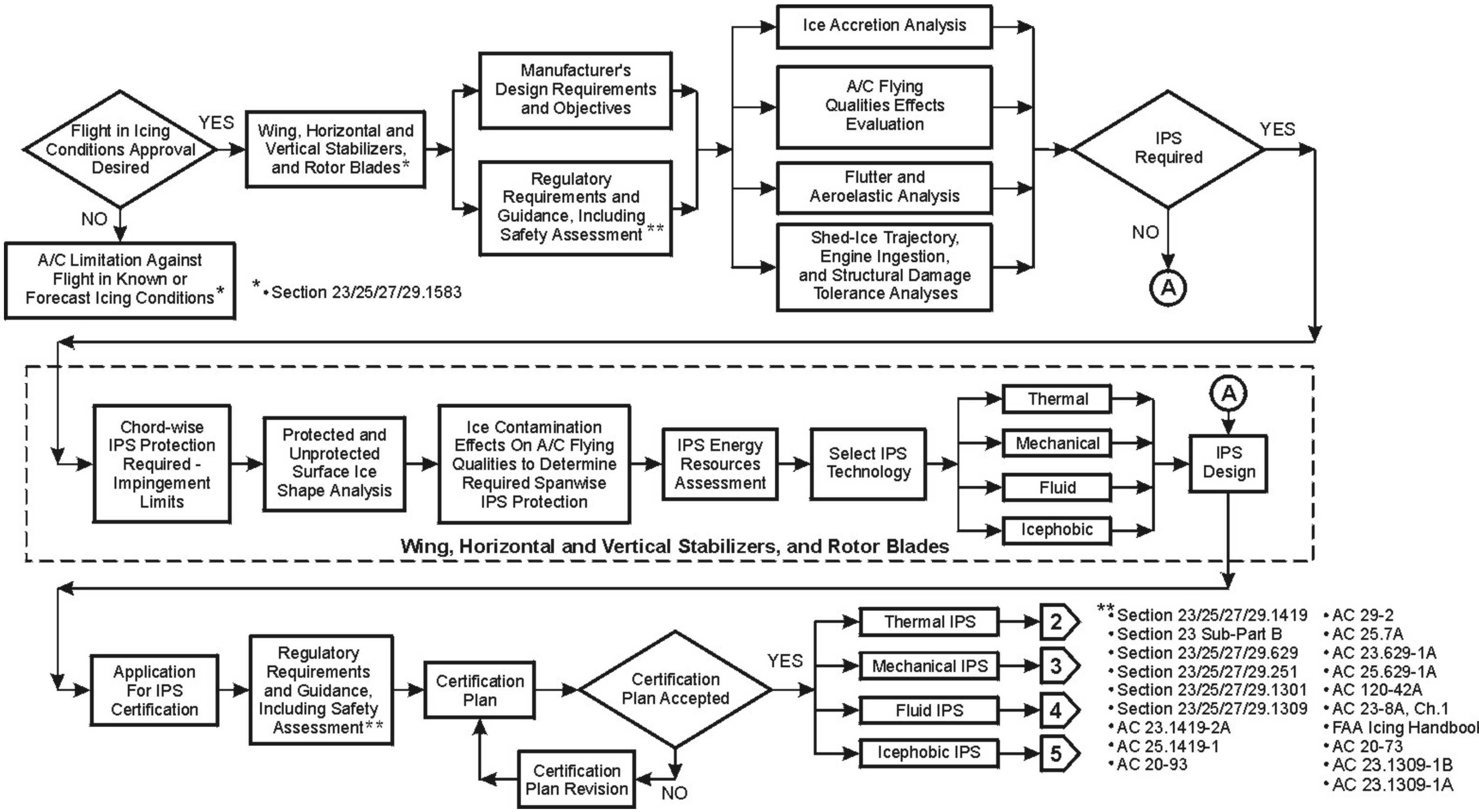


Figure E-2. Typical inflight icing certification processes for wings, horizontal and vertical stabilizers, and rotor blades.

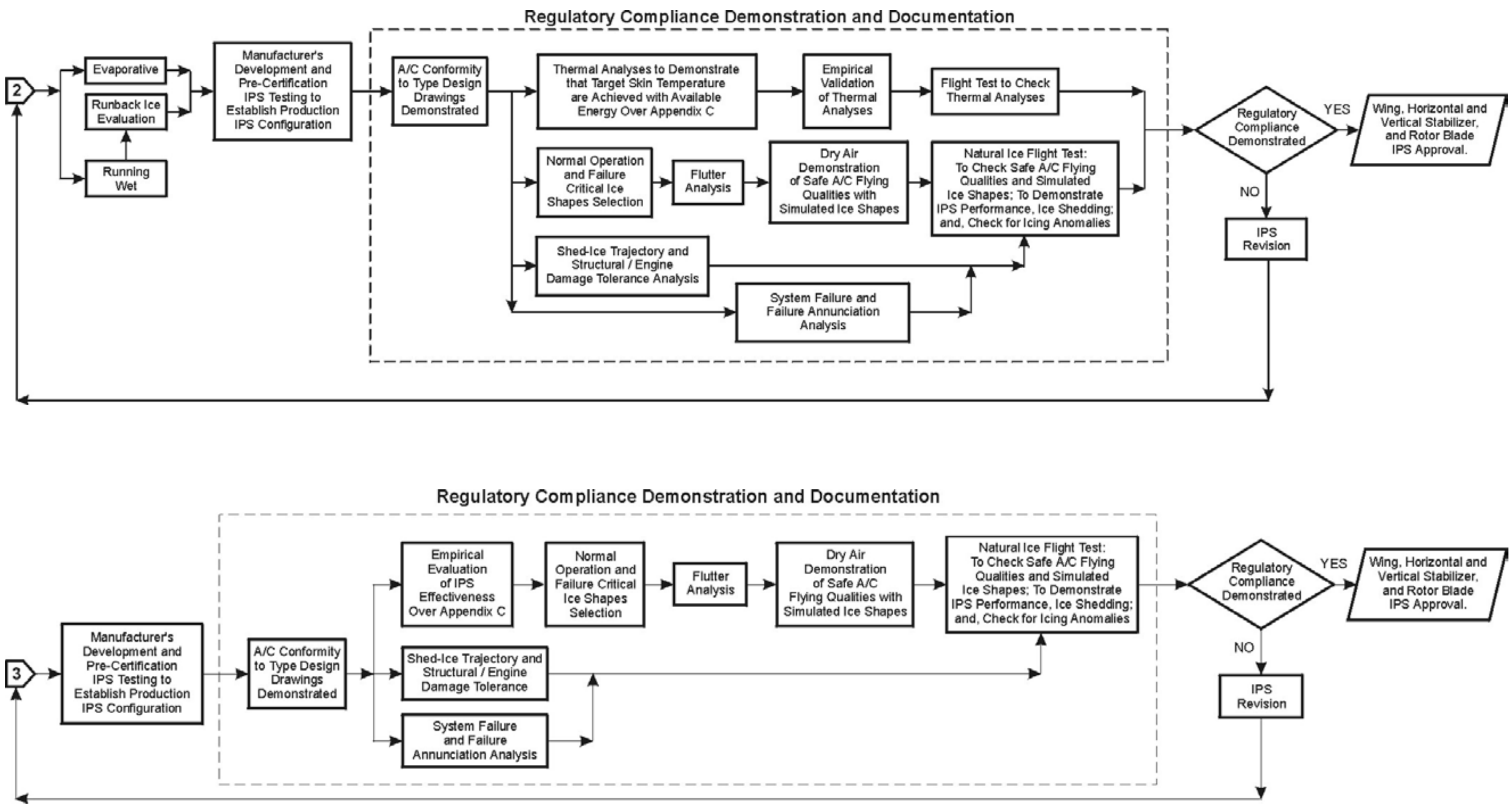
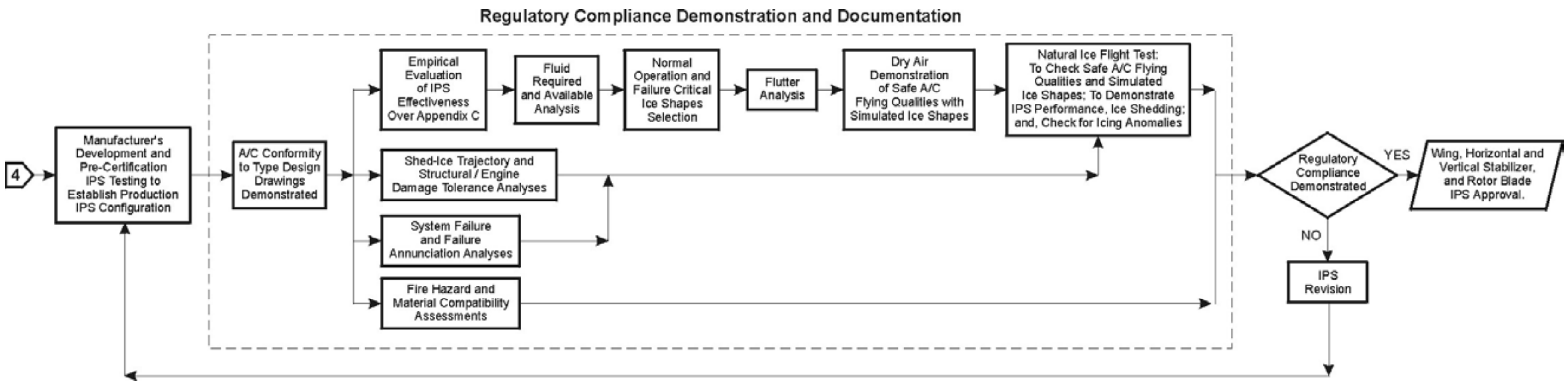


Figure E-2. (Continued)



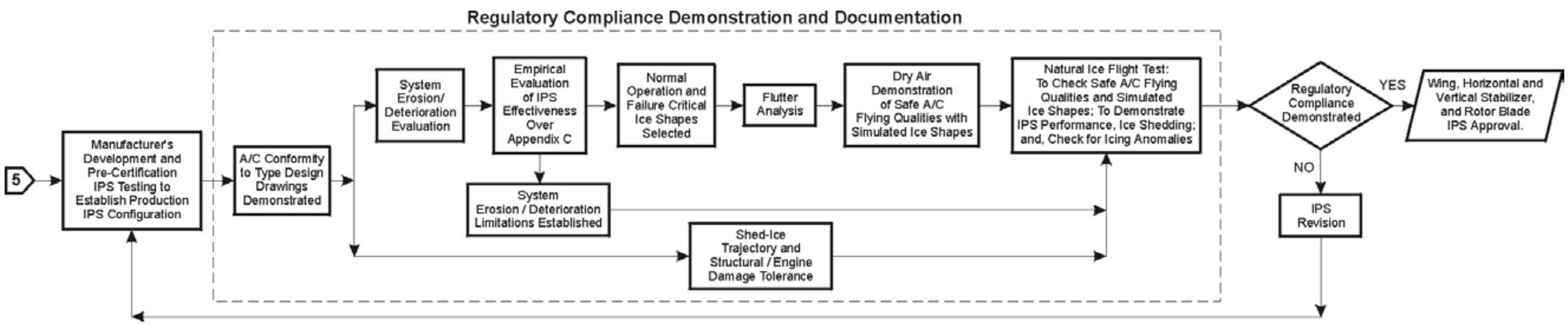


Figure E-2. (Concluded)

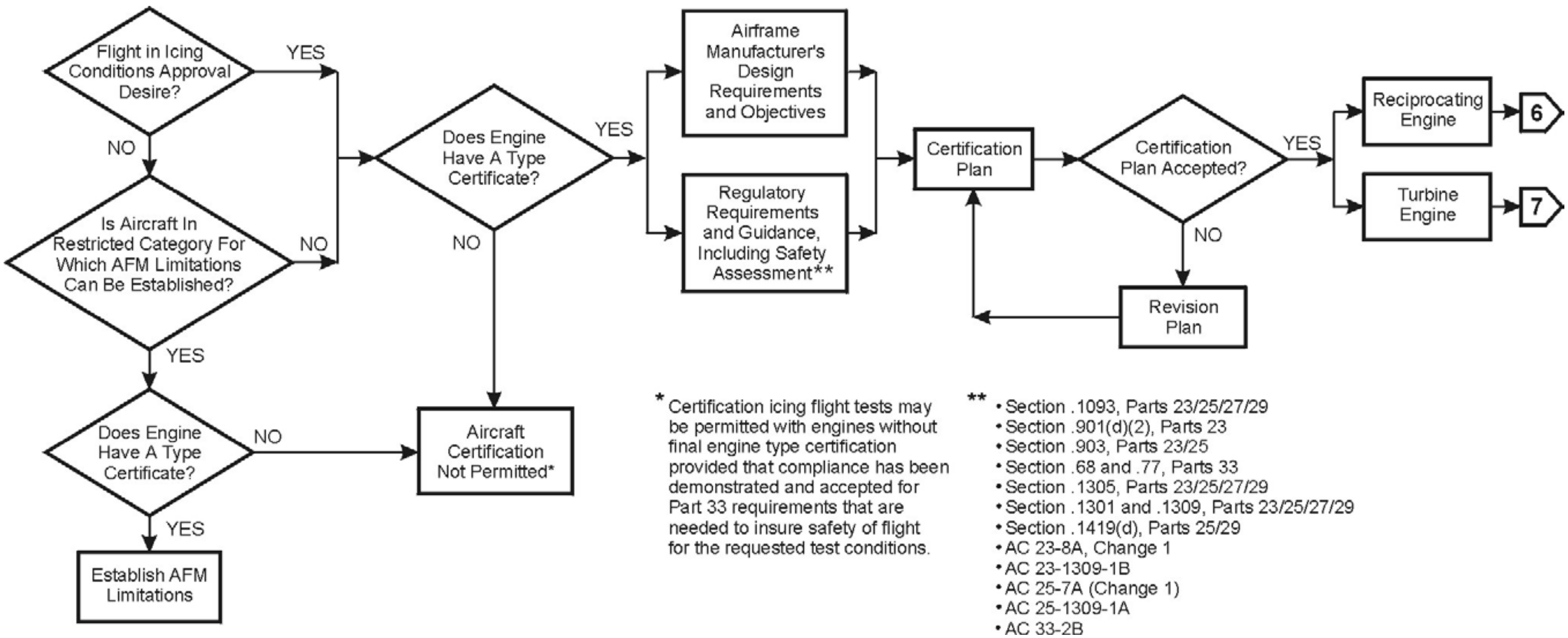


Figure E-3. Typical inflight icing certification process for engine induction systems.

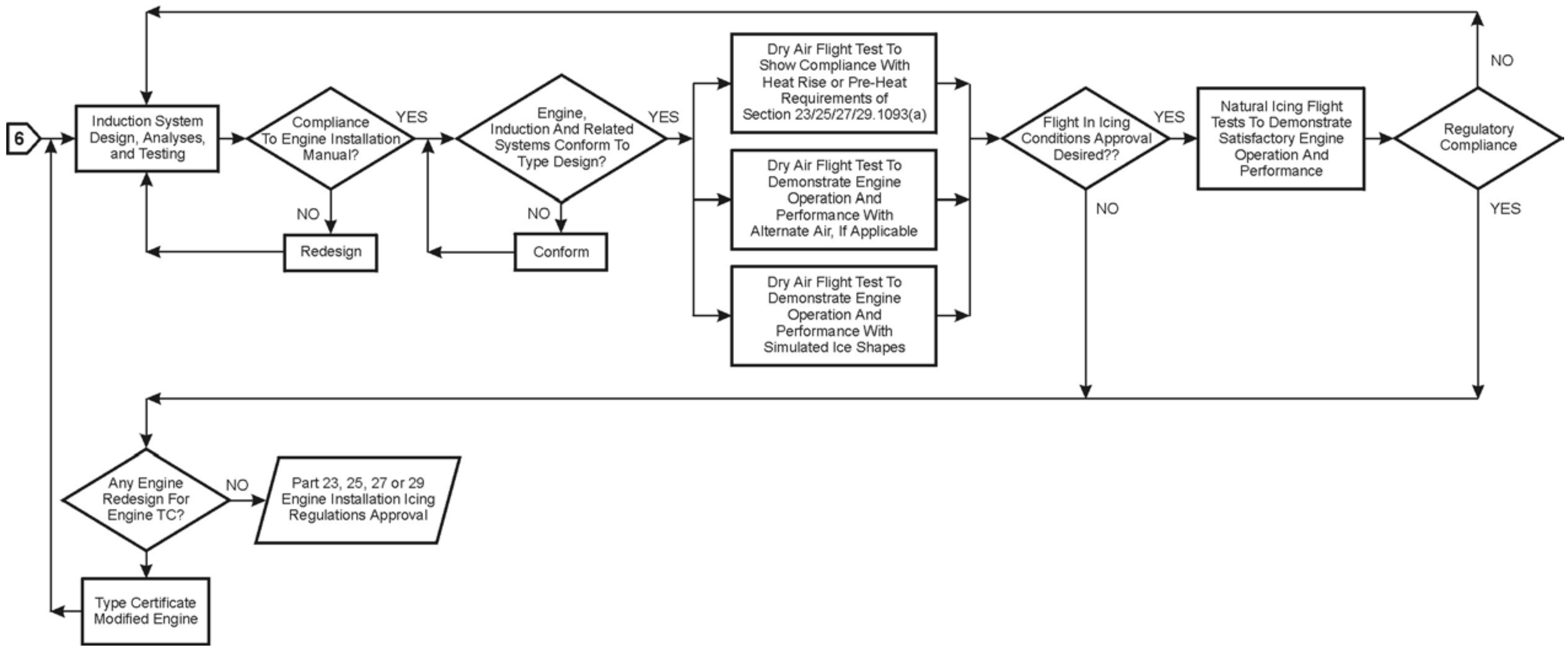


Figure E-3. (Continued)

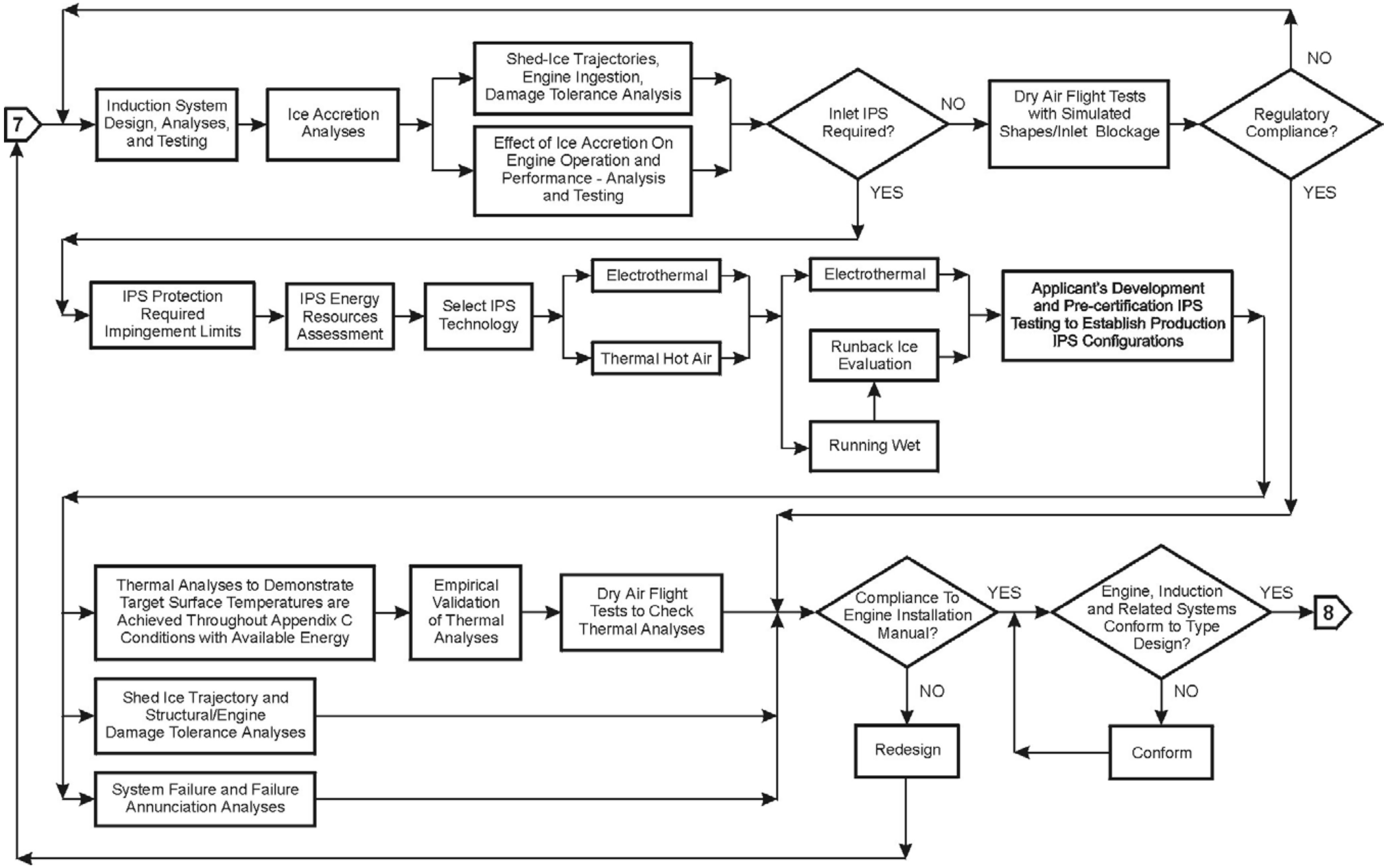
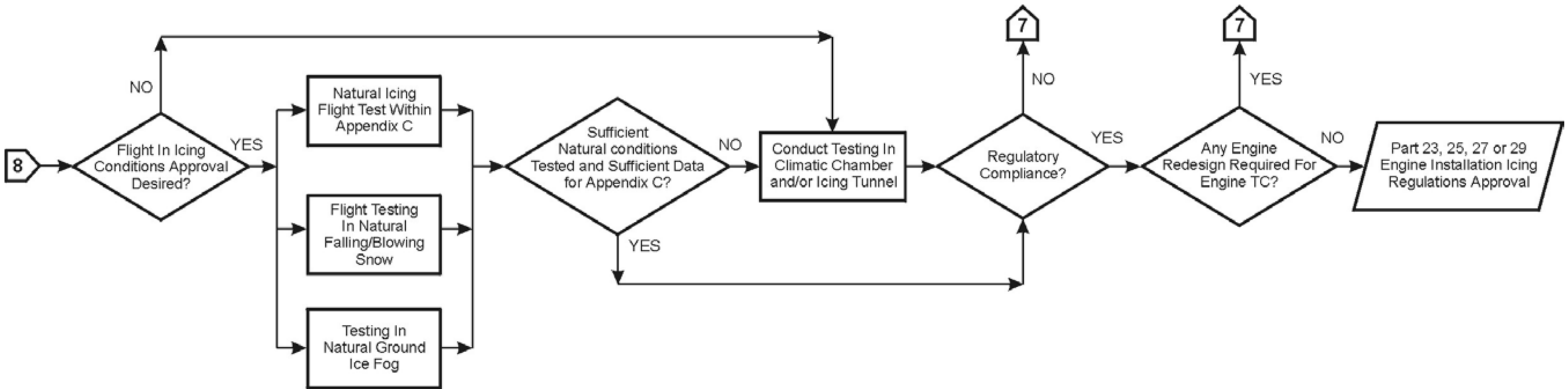


Figure E-3. (Continued)



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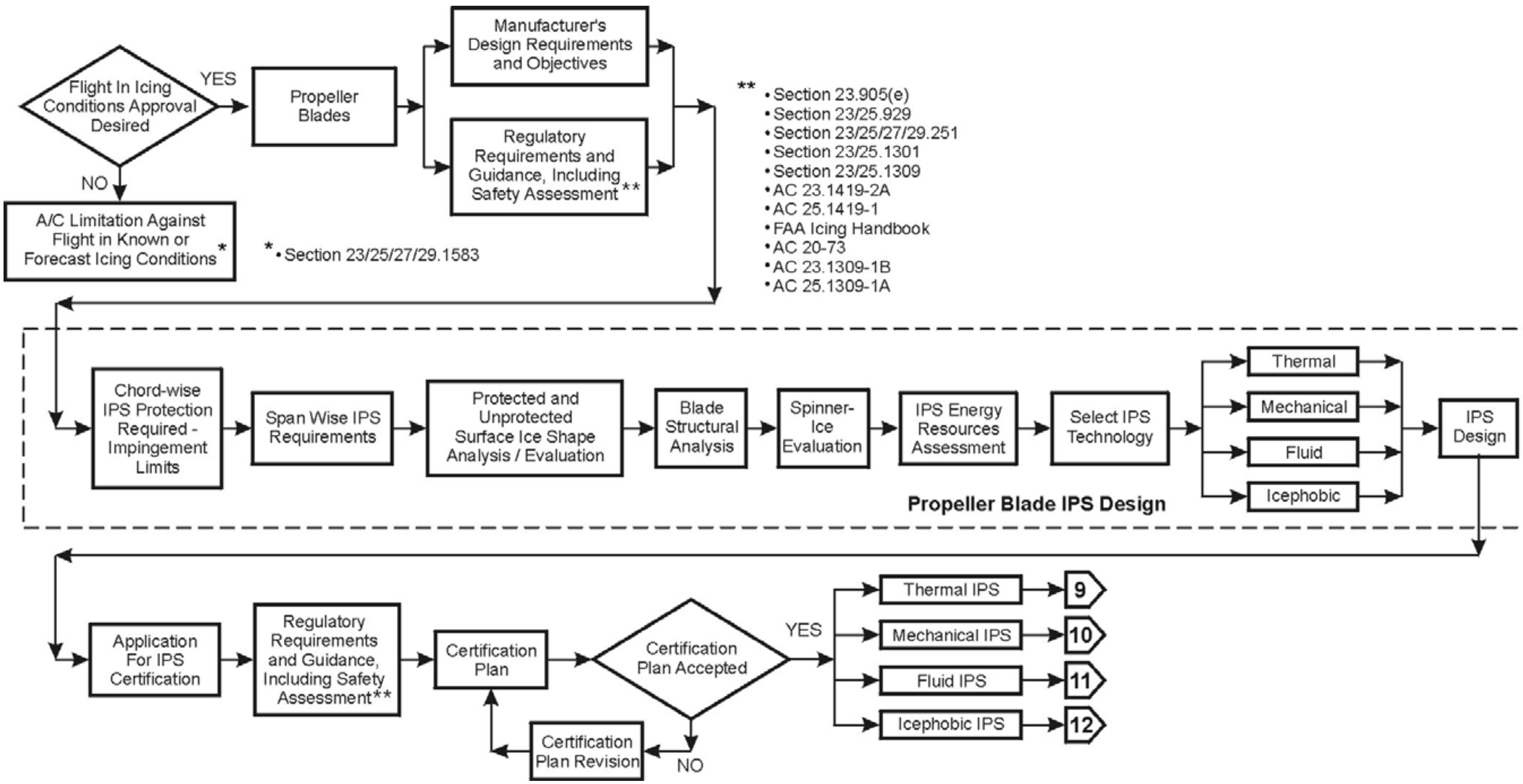
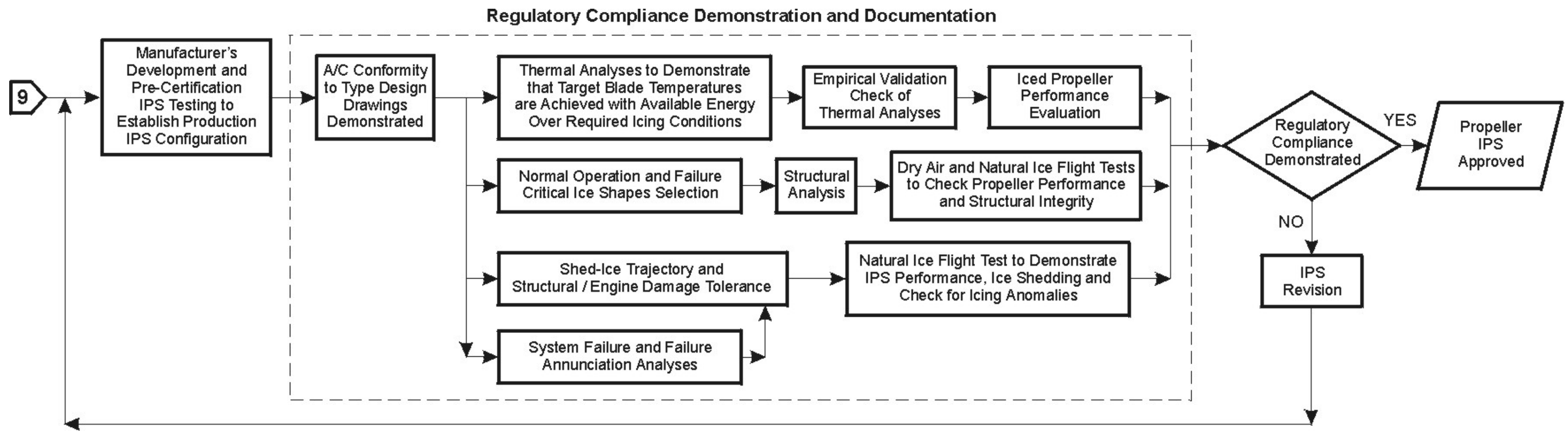


Figure E-4. Typical inflight icing certification process for propellers.



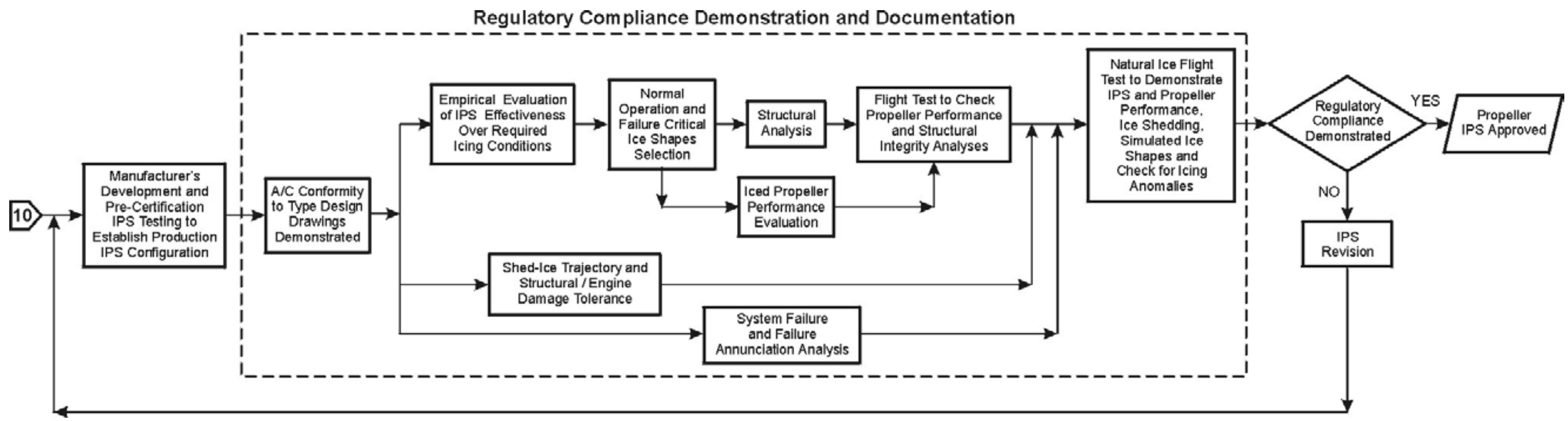
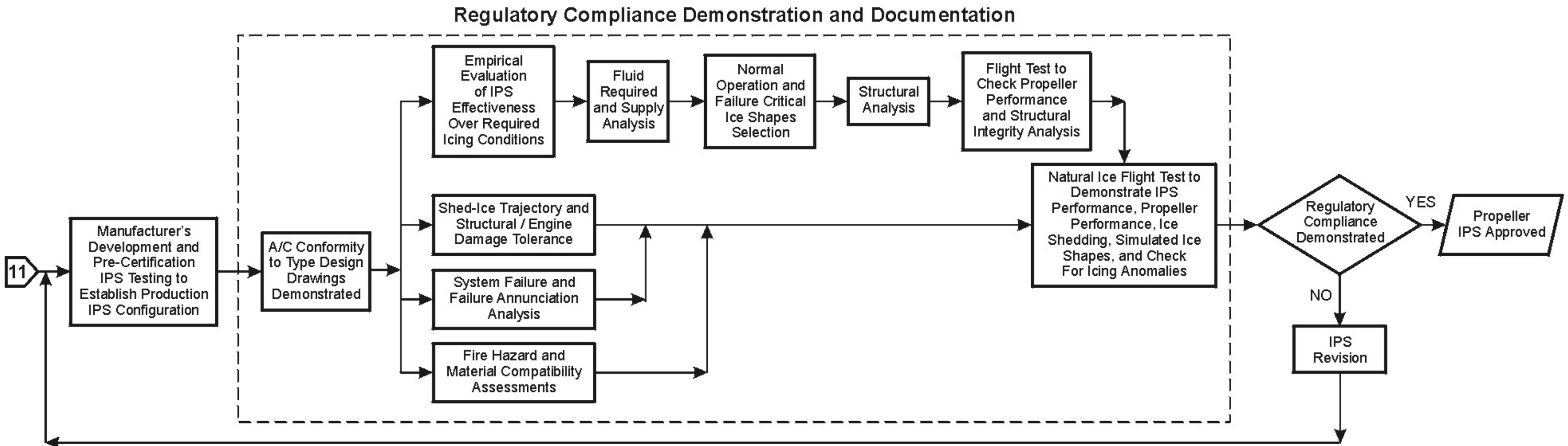


Figure E-4 (Continued)



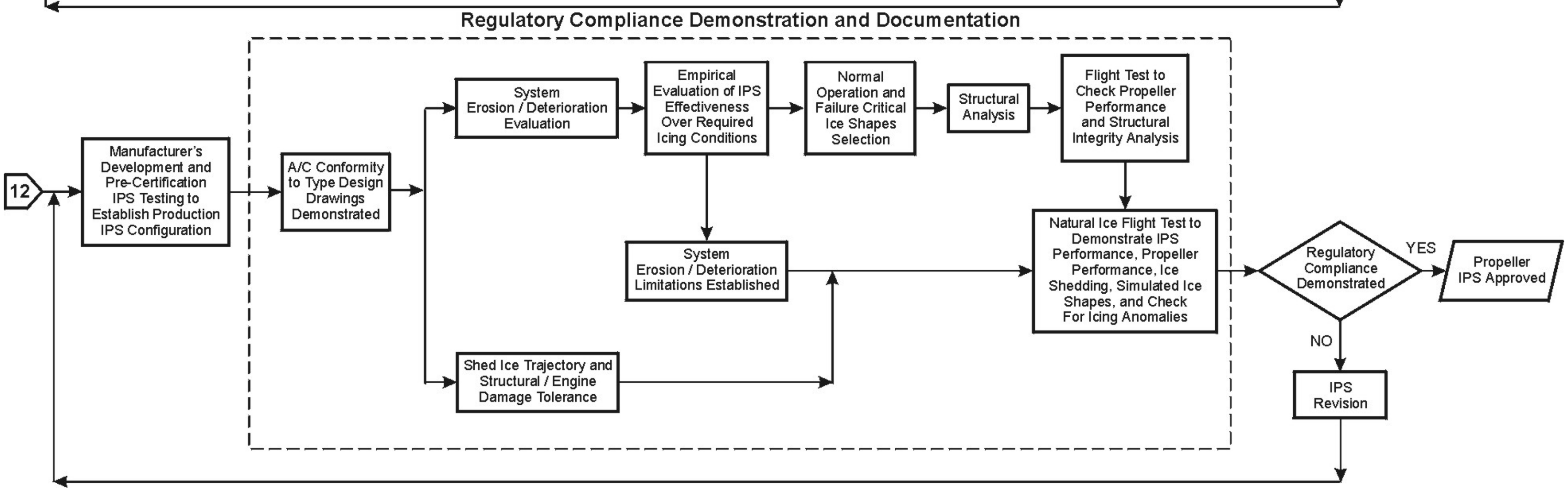


Figure E-4 (Concluded)

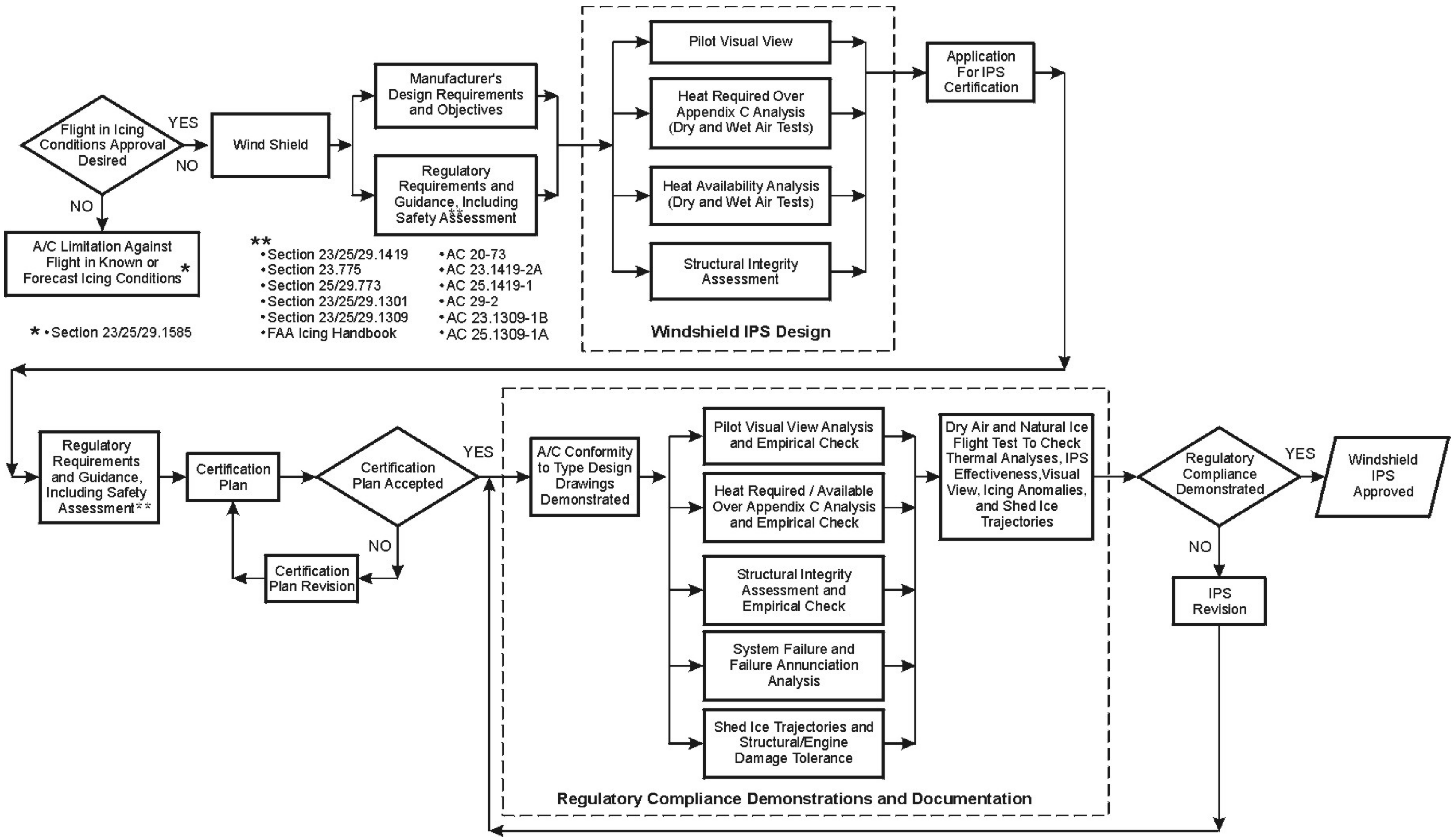


Figure E-5. Typical inflight icing certification process for windshields.

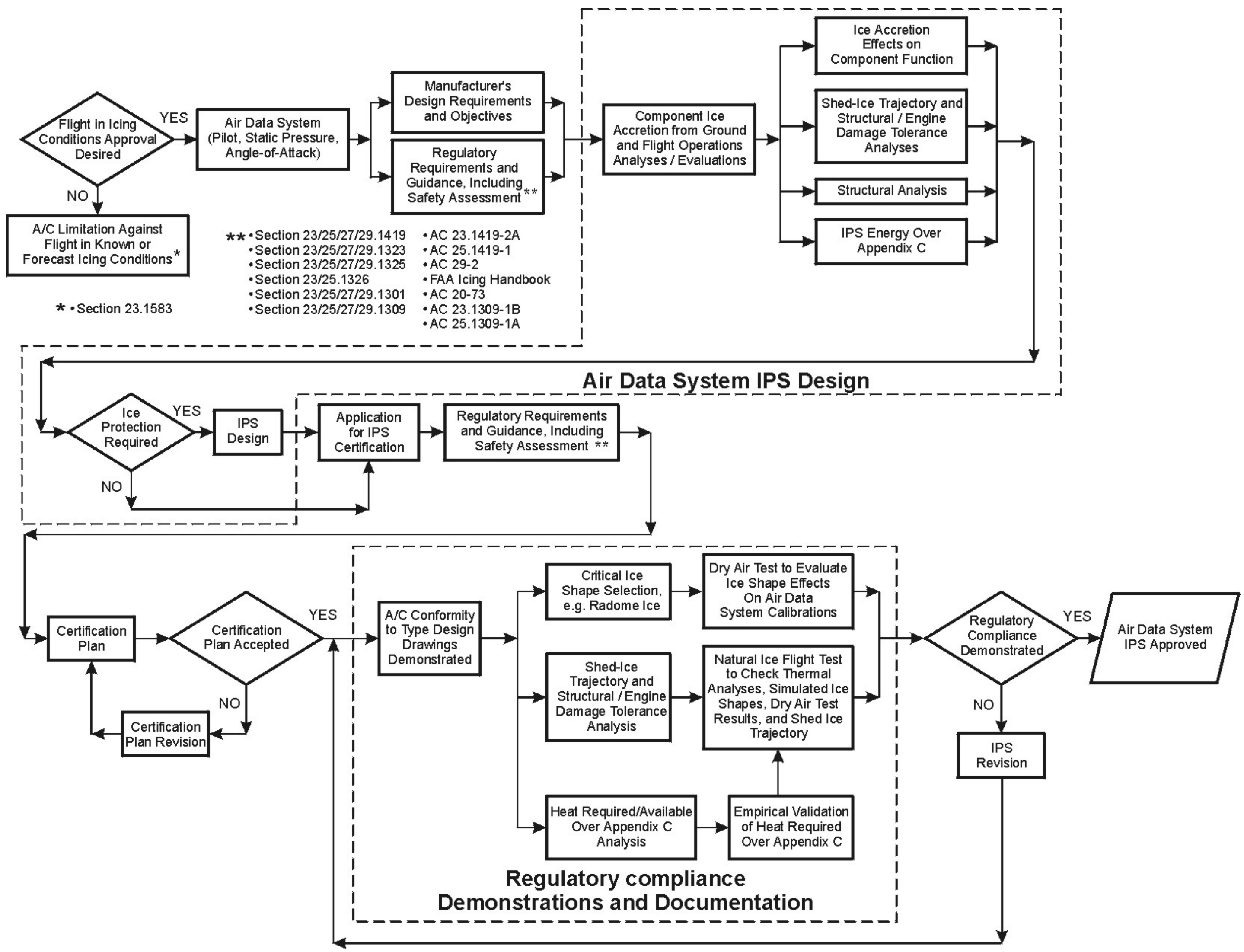


Figure E-6. Typical inflight icing certification process for air data probes/sensors.

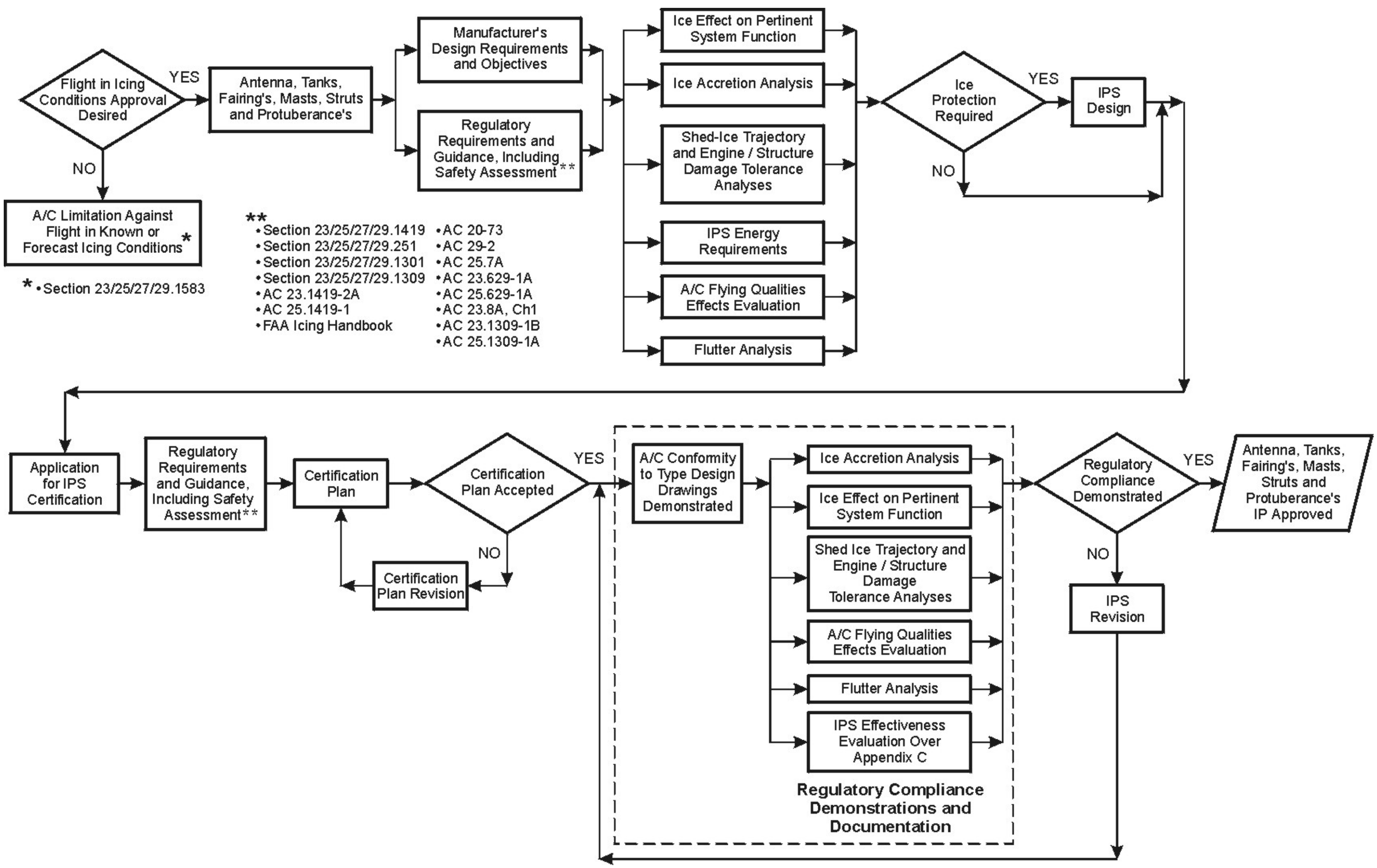


Figure E-7. Typical inflight icing certification process for antenna, tanks, fairings, masts, struts, and other miscellaneous protuberances.

APPENDIX F. OPERATIONAL FACTORS.

F.1 Airplane Operational Factors

The determination of the most critical conditions for which an ice protection system (IPS) is to be designed involves consideration of the operational characteristics of the airplane. Operational regimes such as climb, cruise, hold, and descent are usually investigated at various altitudes. For airplanes with low-speed, high-lift devices, the operational regime during which these devices are used may be the most critical. In other cases, the cruise configuration may be the most critical because of the lift, drag, or control problems associated with the buildup of ice on exposed surfaces. Service experience indicates that holding in icing conditions for as long as 45 minutes is an operational condition that can be encountered. See Appendix G – Icing Conditions Exposure Time for further discussion concerning icing exposure time.

The airplane attitude can contribute to the formation of ice on critical areas. The type and shape of ice formation, and the surface on which the ice forms are, among other things, functions of airspeed and AOA. See Appendix R, sections R.1.1 – Pre-activation Ice Roughness and R.4 – Critical Ice Shapes for further discussion concerning ice formation and critical ice shapes.

For a given set of meteorological conditions, the rate and extent of ice accumulation is a function of flight speed as well as airfoil or body geometry.

Small bodies moving at high speeds encountering large droplets will exhibit high collection efficiency. The flow field associated with larger bodies deflects small droplets, resulting in a smaller collection efficiency.

The ice accretion of an airplane is dependent on the flight speed of the aircraft and the extent of the icing cloud. However, icing tunnel tests show that the accumulations of ice on a surface are not always in a linear relationship with time, especially for accumulations of glaze ice. Ice growth changes the airfoil characteristics and causes a continual change in collection rate above the initial rate; therefore, extrapolating ice accumulations as a linear function of time can be very misleading.

Icing conditions may be encountered inadvertently during operations of airplanes that are not approved for inflight icing operations. Therefore, it is necessary that the powerplants of these airplanes be protected against the effects of ice accumulation as specified in the regulations; however, continuing exposure to icing conditions may cause the airplanes to become incapable of sustaining flight unless approved for continued operations in known icing conditions. See 14 CFR part 23 § 901(d)2) for engines and their installations, and for engine induction systems in accordance with 14 CFR parts 23 and 25 § 1093.

F.2 Rotorcraft Operational Factors

Icing conditions may be encountered inadvertently during operations of helicopters even when not approved for inflight icing operations. Therefore, it is necessary that the powerplants of these helicopters be protected against the effects of ice accumulation as specified in the regulations. However, continued exposure to icing conditions may cause the helicopter to become incapable of sustaining flight unless the rotors are designed and equipped for continued operations in known icing conditions. See Section 10.1 – General and AC 29-2C.

F.3 Engine Operational Factors

The engine operational factors to be considered in determining the most critical conditions are directly related to aircraft operational procedures because changes in airplane speed and attitude are usually accompanied by changes in engine power requirements. The prime factors to be evaluated are the quantity and temperature of air available from the engine for ice protection and the airflow through the engine during the most critical operational mode. For example, the engine flight-idle thrust may need to be increased to insure that the engine is able to provided the bleed air required by the ice protection system. These factors are especially critical for evaluation of thermal IPSs where the heat source is the engine.

The airflow through the engine is critical in terms of the flow field around the inlet lip and the engine inlet. The flow field must be known in order to determine the heat transfer relationships between the heated surfaces, the hot air used to heat the surfaces, and the quantity of water impinging on the surfaces. During some operational modes, the inlet static pressure and temperature are below ambient. In marginal icing conditions, this reduction in temperature may be sufficient to cause ice to form in the inlet.

Engine inlets, inlet air screens, and inlet lips are considered to be more critical with respect to accumulations of ice on surfaces exposed to engine airflow due to the possibility of an appreciable quantity of ice being ingested into the engine. Ice ingestion can cause serious damage to compressor or fan blades. Runback water can also refreeze on unprotected surfaces of the inlet and, if excessive, can reduce engine airflow or distort the flow pattern in such a manner as to excite compressor or fan blades to critical frequencies.

Various engine operational modes have an effect on the collection of ice on propeller surfaces of propeller-driven aircraft. Propeller surfaces are treated similarly to other surfaces in determining the extent and degree of ice protection required. The greatest quantity of ice normally collects on the spinner and inner radius of the propeller. Aerodynamic heating and centrifugal force tend to eliminate ice from the other surfaces. Propeller areas, such as the spinner, on which ice may accumulate and be ingested into the engine should be addressed through the use of inertial separation within the engine or through the use of anti-ice, rather than deice systems, to reduce the hazard of ice being shed into the engine.

In addition to the foregoing, the buildup of ice on unprotected surfaces and the general operational conditions prevalent during icing encounters place further emphasis on the necessity for maintaining an acceptable level of output power.

See guidance information provided by the FAA Engine and Propeller Directorate for details concerning approval of turbine engine induction system ice protection and turbine engine ice ingestion. The Small Airplane Directorate has published Policy Statement ACE-01-23.1093(b) titled “Compliance with Induction System Icing Protection for Part 23 Airplanes,” in the Federal Register dated November 7, 2001. See AC 20-xx (to be published) for information concerning certification of aircraft engines.

APPENDIX G. ICING CONDITIONS EXPOSURE TIME.

To establish the airplane's tolerance to the continuous accumulation of ice on unprotected surfaces and normal operation ice accretion roughness on protected surfaces, analyses, and flight tests should explore stratiform icing clouds (i.e., the continuous maximums shown in Figures E-1 through E-3 of Appendix E of this document) for a period of time representative of air traffic imposed "holding" conditions. The "holding" configurations of the airplane (flaps, gear, drag devices) and recommended operational speeds should be determined and demonstrated to be safe. It is recommended that the tests include a continuous exposure for at least 45 minutes with IPSs operating normally. See, also, the discussion of exposure time for critical ice shapes in Appendix R, paragraph R.4.1 – Considerations for Critical Ice Shapes. Exposure times under system failure scenarios are addressed in Appendix R, paragraph R.3 - Ice Protection System Failure Ice Shapes.

A precautionary note should be provided in the AFM to warn the crew of the possibility that, during prolonged encounters (such as during holding conditions), ice buildup on the unprotected surfaces may not be visible to the crew if that ice buildup affects safe flight of the aircraft.

APPENDIX H. ICE PROTECTION SYSTEMS.

H.1 Ice Protection Technologies and Operating Modes

Ice protection technologies, used as a means of demonstrating compliance with the airframe, engine induction system, propeller, windshields, and air data system sensor surfaces, discussed in Section 6 – Ice Protection Requirements, may be categorized as follows:

- Thermal (hot air and electrothermal)
- Mechanical (pneumatic boots, electro-impulsive)
- Fluid (weeping systems)
- Icephobic

One or more of the following technologies typically achieves protection against ice accretion:

1. Heating the impinging supercooled water droplets to above the freezing point.
2. Using mechanical, thermal, or pneumatic energy to shed accreted ice.
3. Lowering the freezing point of the impinging water below the local air temperature
4. Providing an aircraft component surface that prevents the adhesion of ice.

Hybrid IPSs that combine two or more of the technologies may be developed for specific applications.

Ice protection technologies may be used in either the anti-icing or deicing modes of operation.

Anti-icing systems prevent the accretion of ice on the protection surface, whereas deicing systems are periodically cycled to remove ice that is permitted to accumulate on the protection surface. Ice accumulation is expected on protection surfaces during normal operation of deicing systems, and this surface contamination should be addressed during certification when demonstrating safe flight of the aircraft in icing conditions. Because of possible adverse effects of ice contamination on protection surfaces during normal operation of deicing systems, the mode of operation of the IPS used to demonstrate safe operation of the airplane in icing conditions should be the same as that used during in-service operations. For example, if the IPS is operated as an anti-icing system during demonstration of safe flight in icing conditions, the AFM should not sanction operation of the IPS as a deicing system during in-service operations.

Unless used in a deicing mode, evaporative anti-icing systems have no ice accretion on the protection surfaces or runback ice aft of the protection surface during normal operations in icing conditions. Therefore, there is less change in the aircraft's aerodynamics (compared to the aerodynamics of the uncontaminated aircraft) than that of an aircraft equipped with a deicing IPS. (Note: running wet systems may accrete ice aft of the protection surface in either anti-icing or deicing modes. The runback ice may change the aircraft's aerodynamics.) However, anti-icing systems tend to require greater energy to operate than deicing systems, which can result in significant reductions in available airplane thrust and airplane performance if the engines are used as the source of energy for ice protection. Conversely, in some cases the thrust levels required to ensure evaporative anti-ice protection may not permit aircraft descent per normal operational procedures. In these cases the evaporative system may run wet and runback ice evaluation may be required.

Adverse aerodynamic effects may result from ice accretion roughness on the protected and unprotected surfaces prior to activation of the IPS and prior to the IPS becoming fully effective. (See figures R-1 through R-3 for examples of ice accretion roughness that may exist prior to the IPS becoming fully effective.) Pre-activation ice accretion roughness on these surfaces may be significant. Pre-activation ice accretion roughness aerodynamic effects should be addressed during the airworthiness approval of IPSs. Additionally, intercycle ice roughness/shapes should be evaluated for deicing systems during certification.

Detailed descriptions of ice protection methods and systems are provided in Chapter III of the FAA Aircraft Icing Handbook, DOT/FAA/CT-88/8-1, dated March 1991 [H1]. Most of this material is also available at the Electronic Aircraft Icing Handbook (EAIHB) web site, http://www.fire.tc.faa.gov/aar421/eaihbpg.html. The following provides an overview of aircraft IPSs with comments relevant to their compliance with regulatory requirements.

H.1.1 Ice Protection Technologies

H.1.1.1 Thermal Ice Protection Systems

Thermal ice protection systems may be operated as either anti-icing or deicing systems. The protection surface of a thermal IPS is typically heated to temperatures above freezing. System designs that heat the protection surface sufficiently to evaporate the impinging droplets are called “evaporative” thermal IPSs. Thermal systems that heat the protection surface only to temperatures above freezing, which allows the impinging droplets to flow on the surface, without freezing, are called “running wet” thermal IPSs.

Evaporative IPSs are frequently selected over running wet systems since the freezing of runback water need not be considered. However, evaporative systems require greater thermal energy that may not be available on some aircraft designs. Thermal energy required may be provided electrically or by heated air. Because of the high heat energy required by thermal ice protection, electric thermal ice protection is typically used for relatively small surfaces, such as propellers, air data and “artificial feel” system probes, control surface horns, windshields, carburetor components, and turboprop engine inlets. It is also used for other components or surface areas that are not easily protected with heated air, such as helicopter rotor blades. Heated air for hot air thermal IPSs is typically bled from turbine engines or provided by dedicated heat sources. Heated air or fluids may also be salvaged from other heat sources, including oil coolers and heat exchangers for cabin pressurization air. With the advent of turbofan engines with increased high pressure ratios, use of the engine turbine as a heat source is becoming increasingly limited. This scarcity of thermal energy is leading to an increased use of running-wet thermal IPSs and to a reduction in the extent of the airframe ice protection. For example, on many recent transport airplane designs, no ice protection is provided on much of the wing leading edge, and none on the horizontal and vertical stabilizers.

The thermal energy required for safe flight of the aircraft in the applicable icing environment must be available. Energy availability must be determined. This can be accomplished through flight tests in critical icing conditions. This approach is costly, time consuming, and runs the risk of not finding critical icing conditions. Alternatively, thermal analyses, verified by dry air and natural icing flight tests with instrumented aircraft, may be used to verify the adequacy of the heat source. These analyses tend to be very complex since the heat required is a function of many parameters, including:

- Evaporation of the impinging water loading
- The target surface temperature distribution for a running-wet IPS.
- External airflow speed and temperature
- Heat distribution on the protection surfaces
- Heat transfer between the free stream and heated surfaces
- Radiant heat transfer
- Internal heat transfer (for heated air systems, internal heat transfer may be a function of engine power settings, altitude, ambient temperature, and system losses)
- The heat conduction and convection coefficients of the protection surface material

Computer codes, analytical methods, or previous experience may be used in the analyses to estimate the required heat. See SAE ARP5905 [H2] for guidance relative to the use of computer codes. See [H3 through H5] for further information relative to methods of determining the required heat.

Typically, thermal analyses are performed for specific aircraft components; however, these individual analyses should be integrated into a total systems analysis, including internal duct heat losses (for hot air systems), to determine the total system heat requirement and to demonstrate the availability of the required heat. Analysis should also demonstrate that structural temperatures resulting from the IPS, including ducting immediately downstream of the engine bleed ports, do not cause fire hazards or adversely affect the integrity of structural material.

Because of the approximations that may be necessary in the analyses, empirical corrections may be determined using icing wind tunnels and/or icing tankers. (See SAE ARP5903 [H6] and ARP5904 [H7].) Dry and wet air flight tests should be used to verify the heat needed to maintain the desired surface temperature of the complete IPS.

Due to the influence of the water loading on the energy required for thermal IPSs, the icing conditions defined by Appendix C may be considered more important for determining the design of thermal IPSs than mechanical systems.

Commonly, the heat for a thermal IPS is provided by dedicated heat sources, electric generators or alternators driven by the engines, or by extraction from the compressor stage(s) of turbine-powered aircraft or on rotorcraft, by electric generators or alternators driven by the main transmission. The needed thermal energy may be significant and can result in significant loss of engine thrust and a significant increase in fuel flow. The bleed air extraction required by the ice protection system should be verified against the engine installation handbook for compatibility. While most engines incorporate flow limiting devices in the bleed ports, these devices are usually designed to choke at higher flows than those expected for normal operation. The aircraft performance losses resulting from the engine-bleed air must be shown in the AFM, as applicable. Also, at low thrust levels, the needed bleed air may not be available, requiring the engine to be operated at higher thrust levels during phases of flight such as descent. Also, during one-engine-inoperative operations, sufficient bleed air may not be available to satisfy the needs of the IPS, resulting in IPS design or operating procedure changes. For some type designs, use of the auto-throttle may be required to maintain the engine thrust/airflow necessary to provide the thermal ice protection heated bleed air during one-engine-inoperative operations and during descent. Components of thermal IPSs may be operated sequentially or periodically as a deicing system, to minimize energy requirements. The adequacy of the heat source to provide satisfactory ice protection for safe aircraft operation in icing conditions must be demonstrated. Required system operating procedures must also be included in the AFM.

"Running wet" thermal airframe IPSs may result in runback ice accretions. Runback ice accretions should be considered as part of the surface roughness expected during normal operations in icing conditions. Ice accretion shapes resulting from runback water are difficult to predict analytically. Flight testing in natural icing conditions, in artificial icing conditions, or in an icing wind tunnel test may be required to determine the extent and characteristics of runback ice. See [H3 through H5] for additional information relative to design methods that will minimize runback icing.

Similar thermal analyses should be performed to demonstrate the adequacy of electrical energy sources to provide sufficient thermal energy to protection surfaces during inflight icing operations within the applicable icing environment. Attention should be directed to ensuring that compliance is demonstrated for related regulations, such as for pilot visibility, air data system probes, propellers, and induction systems. Consideration should be given to the availability of ice protection and safe aircraft operation in icing conditions when failures of electric generators are evaluated.

Consideration during the system failure analysis should be given to the engine bleed air valves and controls, the cross-over duct valve and control, and system sequencing equipment to ensure symmetric ice protection on both sides of the aircraft during one-engine-inoperative operations. Also, the reliability of the protection surface temperature controls should be reviewed to ensure the structural integrity of the protection surface.

Protected surface roughness—resulting from ice accretion that accumulates prior to when the IPS becomes fully effective after following AFM procedures—should be evaluated to ensure safe flight as defined by the applicable requirements (see Section 6.2 – Safe Flight in Icing Conditions). See Appendix R, section R.1.1 – Pre-Activation Ice Roughness for additional information relative to pre-activation ice shapes and section 8.2 – Tests for means to evaluate aircraft safe flight with pre-activation ice accretion.

Airframe thermal IPSs may be operated in the deicing mode, often in an effort to minimize ice protection energy requirements. As with any deicing IPS, intercycle ice accretion on the protected surfaces will occur with this mode of operation. The resultant intercycle ice accretion roughness should be considered present during normal operation of the IPS and should be assessed when safe operation of the aircraft is demonstrated for inflight icing operations. Attention should be given to adverse aerodynamic effects that may be caused by sequential deicing that results in asymmetric ice accretion. Considerations presented in Appendix P – Ice Shedding for the presence and shedding of the intercycle ice roughness should also be addressed when thermal IPSs are operated in the deicing mode.

Ice protection of air data sensors is typically accomplished using electro-thermal ice protection. With local thermal ice protection, ice bridging may occur. Also, for running wet thermal ice protection systems, runback ice may grow forward, capping the heated surface. These issues should be addressed during the design of the thermal ice protection system.

Information concerning rotor blade ice protection and rotorcraft ice protection system design is provided in [H8].

H.1.1.2 Mechanical Ice Protection Systems

Mechanical IPSs use mechanical energy to shed ice from protection surfaces. Dynamic inflation/deflation and flexing of elastic tubes or dynamic flexing of surfaces may apply the mechanical energy. Mechanical force may also be transmitted through aircraft surfaces to fracture and break the adhesion of accreted ice on protection surfaces. The freestream airflow shear force and the mechanical energy imparted to the ice then cause the ice to shed. Because ice is allowed to accrete on the protection surface before being shed, these systems operate as deicing systems.

Pneumatic deicing boots use rapid inflation, deflation, and flexing of elastic tubes to impart the ice shedding mechanical energy. The elastic tubes may be installed streamwise or chordwise.

The mechanical energy may be delivered electrodynamically by dynamically charging ribbon-like coils rigidly supported beneath the protection surface. The strong, short-period electromagnetic field formed by the charged coils induces eddy currents in the aircraft surface directly above the coil, which in turn causes the aircraft skin to respond to the strong repulsive electromagnetic force field. The small but rapid skin deflection of the electro-impulse deicing (EIDI) systems imparts a sharp force to fracture and eject adhering ice.

Alternatively, the de-bonding and ejecting mechanical force of an electro-expulsive deicing system (EEDS) can be delivered by impulsive movement of the protection surface. This impulsive movement is caused by electrical current being pulsed in opposite directions through closely-spaced parallel conductors, or conductive layers, embedded in a non-conducting elastomeric matrix blanket beneath the protection surface. An eddy current deicing system (ECDS) provides an impulsive movement of the protection surface by a reaction to electrical current being pulsed through flattened planar coils embedded within and spanwise along the leading edge of the protected aircraft component.

Note that deicing systems such as EIDI, EEDS, and ECDS, may produce strong electromagnetic fields. Consideration should be given to the interference of these electromagnetic fields with the operation of other electrical or magnetic equipment, such as high-lift devices' magnetic near-far sensors, magnetic compasses, and shielding of wiring and electrical controls (14 CFR parts 23 and 25 §§ .1327, .1351, and .1547). Additionally, these types of systems typically operate with brief, but very high levels of energy. These high energy levels could produce a significant ignition source during failure conditions of either the system or in combination with external events (e.g. bird strikes). Aircraft level flammable fluid and system safety requirements (14 CFR parts 23, 25, 27 and 29 §§ .853, .863 and .1309, 14 CFR part 25 § .981, and SFAR 88) should be evaluated with installation of these types of systems in proximity to flammable fluids.

An emerging technology uses the pressure of oxygen and hydrogen generated by electrolysis of water melted at the interface of the accreted ice and the protection surface to de-bond and eject adhering ice. This technology has not yet reached a level of maturity to be considered for application. Of all these mechanical ice protection technologies, pneumatic deicing boots are most commonly used.

The ice shedding efficiency of mechanical IPSs depends on many factors, including:

- The adhesive strength of the bond between the ice and the protection surface.
- The shearing force of the local airflow.
- The fracture strength and modulus of elasticity of the adhering ice.
- The ability of the elastic protective surface to fracture the ice into sufficiently small particles to be sheared from the protective surface by the local airflow.
- The ability of the mechanical force and elasticity of the surface material to peel and eject the fracture ice.
- The characteristic dimensions of the IPS components.
- The variation of the protection surface modulus of elasticity and pliability with temperature.
- The characteristics of the applied mechanical force.
- The surface condition of the protection surface.
- The intercycle interval.
- The characteristics of the pneumatic air pressures (inflation and deflation, and inflated dwell air pressure) for pneumatic deicing boots.

Because of the many variables involved, the ice shedding efficiency of mechanical IPSs tends to depend on the aircraft design.

Considering current analysis capabilities and the inability to test full size aircraft in icing wind tunnels, full-scale flight testing in natural or artificial icing conditions may be necessary to evaluate the ice shedding efficiency of mechanical IPSs. SAE ARP5904 [H7] provides useful information relative to the use of icing tankers for evaluating deicing efficiency. Section .1419 of 14 CFR parts 23, 25, 27, and 29 requires flight testing in the applicable icing environment to demonstrate that these systems can ensure safe operations in inflight icing conditions. Changes to the IPS that modify the system's ice shedding efficiency should be evaluated relative to the changed system's ability to ensure safe operations in inflight icing conditions.

See Appendix P relative to possible adverse effects the may result from the shedding of ice from mechanical ice protection systems.

The adhesion of ice to the boot surface can be significantly reduced by application of an icephobic material. However, these materials need to be re-applied periodically to ensure their effectiveness. Because of the difficulty of ensuring the use of these materials during normal, in-service operations, and because of the variability of icephobic effectiveness as the material erodes from the boot surface, the benefits of using icephobic material on the deicing boots should not be included when demonstrating safe flight in icing conditions.

The protection surface roughness resulting from operation of the mechanical IPS is a function of the residual ice that remains on the surface after cycling of the deicing system and the intercycle ice that accumulates between cycles. This protection surface roughness should be considered present during normal operation of the aircraft in icing conditions. The residual ice remaining after exiting icing conditions and after cycling of the deicing system should be considered relative to the aircraft's flying qualities and stall protection system until the flight crew can determine that no residual ice remains on the aircraft. Characteristics of the normal-operations protection surface roughness should be determined by component testing in an icing wind tunnel, or during natural or artificial icing flight tests and provided by the applicant. The character of the normal-operation protection surface roughness varies with the mechanical IPS's design, how it is operated, the aircraft configuration, and the icing conditions. Appendix R, section R.1.1 – Pre-Activation Ice Roughness provides additional intercycle ice guidance information.

Deicing boot ice bridging and the ice shedding characteristics of early deicing boot designs have led to recommended procedures that deicing boots be cycled after ¼ to 1½ inches of ice have accumulated on the boot surface. This practice originates from the belief that a bridge of ice could form if the boots are operated prematurely. Classical deicing boot ice bridging occurs when a thin layer of ice is sufficiently plastic to deform to the shape of the inflated deicing boot tube without being fractured or shed during the ensuing tube deflation. As the deformed ice shape hardens and accretes additional ice, the deicing boot becomes ineffective in shedding the "sheath" of ice. Icing tunnel and natural icing flight testing have shown that the concern over ice bridging is considered unnecessary with modern boots. Modern boots are defined as those that use small diameter tubes (up to 1.75 inches), nominal operating pressures of 15 psig and higher, and fast inflation and deflation times..

It is difficult for the flightcrew to accurately determine the thickness of the ice by visual observation. Therefore, the recommended AFM procedure for boot operation should be to operate the boots at the first sign of ice accretion and not wait for a specific amount of ice to accumulate.

Regardless of when the ice protection system is activated the ice may not shed completely after each cycle of the boots. Therefore, the resultant boot intercycle, residual, and preactivation ice should be considered to be present during normal operation of the IPS. This normal-operation ice contamination should be evaluated when safe operation of the aircraft is demonstrated for inflight icing operations.

The critical intercycle ice roughness may be sensitive to temperature and altitude. At colder temperatures the adhesive characteristics of rime ice are high, and rough, "alligator-skin-like" surface roughness may occur as fractures of the residual ice act as "seeds" for additional ice accretion between deicing boot cycles. Also, the flexibility of boot material may be affected by temperature. Near freezing temperatures often result in aerodynamically adverse ice ridges that develop from residual ice along the trailing edges of individual deicing boot tubes. These ridges of ice result from residual ice that remains on the aft portion of individual deicing tubes. The residual ice remaining on the aft portion of the tubes results from the ice not being shed by the lower local airflow velocities (and shear) when the tube is inflated. The localized ice accretion acts as an efficient ice collector for the impinging and runback water during both the periods of tube deflation and inflation.

Many inflight icing accidents and incidents occur during near-freezing icing conditions. Since the boot air supply may be predicated on gage air pressure, ice shedding performance and intercycle ice roughness should be evaluated throughout the temperatures and altitudes defined by Appendix C, or as limited by the aircraft's flight envelope. Because boot pressure is dependent on bleed mass flow, dry air flight testing should demonstrate boot operation and pressures at minimum engine power settings and altitudes defined by 14 CFR parts 25 and 29 Appendix C, or as limited by the aircraft's operational envelope. A minimum engine power setting, if determined, shall be published in the AFM. Deicing boot air pressure variation resulting from air pressure regulator tolerances should be addressed when the effectiveness of the deicing boots is demonstrated. Also, some system cockpit annunciation lights are set below these tolerances. Ice shedding performance and intercycle ice roughness should be determined at these lower pressures.

Consideration should be given to the potential for accumulation of liquid water in the pneumatic deicing boots, which could freeze within the system and prevent proper operation of the boots. The pneumatic and boot arrangement should be examined for low points, which may collect water, and consideration should be given to the installation of water drainage points. Periodic inspection and drainage procedure instructions should be provided in the appropriate manuals. Drainage or "weep" holes have been found to be subject to blockage on some aircraft and water/air separators and/or heaters have been found necessary in these aircraft. An evaluation of the effectiveness of water/air separators and/or drainage holes should be accomplished by flying through rain, followed by flight at altitudes with temperatures below the freezing point.

System failure analyses of mechanical IPSs should include an assessment of the deicing boots' pressure control valves, and the annunciation of IPS failures to the flight crew.

The deicing effectiveness of pneumatic deicing boots is a function of the dynamics of the boot's inflation and deflation, the flexibility of the boot material, and the adhesion of the ice to the boot surface. Their effectiveness should be demonstrated in flight throughout the altitude range of the required icing conditions. Boots should be operated at the coldest temperature of the required icing conditions regime for proper operation of the boots and to verify boot structural integrity.

Operation of the boots should not result in hazardous effects on aircraft performance and handling qualities. Because inflated leading-edge pneumatic deicing boots distort the surface's leading-edge contour and may change surface flow conditions, tests should be performed to evaluate possible hazardous changes to handling qualities and performance. These effects may be evaluated by operating the boots at speeds ranging from stall speed to $(V_{NE}+V_D)/2$ or $(V_{MO}+V_D)/2$ and observing the aircraft's behavior. Any deicing boot operation limitations, such as altitude, temperature, airspeed, aircraft configuration, or flight phase, should be included in the AFM, as well as anomalous aircraft behavior associated with operation of the deicing boots.

H.1.1.3 Fluid Ice Protection Systems

Fluid (freezing point depressant) IPSs introduce a freezing point depressant agent, typically a glycol compound, onto the surface at the leading edge, causing the impinging water to have a freezing point lower than the local airflow temperature. The impinging water mixture then evaporates or is shed from the surface. The freezing point depressant may be introduced on the protection surface:

- As a fluid that has been pumped through a porous surface,
- Channeled along the protection surface in grooves by centrifugal force,
- Sprayed from external spray bars, or
- Contained in compounds (such as grease) that have been applied to the protection surfaces, such as propellers.

This ice protection technology is historically associated with products developed during World War II by TKS Ltd., a conglomerate of Tecalemit Ltd., Kilfrost Ltd., and Sheepbridge Stokes formed in Great Britain. However, systems manufactured by other companies are in current use. These systems use a liquid freezing point depressant that is pumped through the porous skin of protection surfaces, and they may be used in either the anti-icing or deicing mode. In addition, these systems have the potential of being very simple and reliable; however, the availability of the protection is limited by the supply of fluid. Consideration should be given to ensuring that the supply of fluid is sufficient and to evaluating the effectiveness of the system within applicable icing conditions for all phases of flight and applicable aircraft configurations. Also, consideration must be given to fire hazards and possible fire extinguisher requirements associated with the ice protection fluid (14 CFR part 23 §§ .863 and .1199(b)).

H.1.1.4 Icephobic Ice Protection Systems

Icephobic materials are occasionally considered for use as an aircraft IPS. Typically the hydrophobic material is applied to the protection surface, with the objective that the supercooled water and ice will be unable to adhere to the surface. To date, this ice protection technology has not been commercially developed. As discussed in paragraph H.1.1.2 – Mechanical Ice Protection Systems, icephobic silicon compounds may be used to supplement the ice shedding effectiveness of mechanical IPSs, however no credit may be taken for its use during approval of the IPS since maintaining effective use of the compound is difficult to control.

H.1.2 Ice Protection System Operation

Common to all IPSs is a means by which the system is activated to ensure safe flight in icing conditions. This may be accomplished by:

- The flight crew visually observing the presence of icing conditions or ice accretion on monitored (if observable) airframe surfaces and then activating the IPS.
- The flight crew being alerted by some means that icing conditions or ice accretions exist on monitored airframe surfaces that will require crew action to activate the IPS.
- Automated operation of the IPS by a means that detects the existence of icing conditions or airframe ice accretions on monitored surfaces.
- Operation of the engine IPS based on visible moisture and temperatures specified in the AFM or RFM.

Activation of the airframe IPS should also, as necessary, increment the stall protection schedule to ensure adequate stall margin for flight in icing conditions.

Requirements have been established to ensure pilots are provided necessary information and operating limitations for safe operations in inflight icing conditions, in accordance with 14 CFR parts 23, 25, 27, and 29 §§ .1525, .1583, and .1585; and parts 23, 27, and 29 § .1559. Part of this information includes informing the flight crews of required or recommended means and procedures for operating the aircraft's IPS.

Detection of aircraft icing and icing conditions is accomplished on some aircraft by observation of ice accretion on reference aircraft surfaces. These surfaces include windshield wiper blades, windshield posts, and other small protuberances that are efficient ice collectors and that tend to collect ice before ice accretion is observable elsewhere on critical aircraft surfaces. Reference surfaces used as airframe icing cues should indicate the presence of hazardous icing prior to or simultaneously with the ice accretion on monitored surfaces. Adequate lighting, other than a flashlight (because of crew workload), must be provided for detecting ice during night operations. 14 CFR §§ 23.1419(d), 25.1403, 27.1419(e), and 29.1419(e), require that means be provided for illuminating or otherwise determining the formation of ice on parts of the wings that are critical from the standpoint of ice accumulation. Consideration should be given to illuminating ice evidence probes for operations at night. The illumination should be demonstrated to provide adequate visibility, without excessive glare, reflections, or other distractions, in and out of clouds. If cues of icing are not visible at night, aircraft approved for flight in icing conditions should be limited from operations at night.

For some aircraft, no icing cues are visible from the normal work position of the flight crew. For those aircraft, and generally for operation of engine ice protection, visible moisture and temperatures colder than those selected by the applicant may be used as indication of icing conditions. The threshold selected by the applicant must ensure that no hazardous amount of ice will accrete on the engine induction system or other critical surface at a temperature above this limit. These conditions should be specified in the AFM. Alternatively, approved ice detectors, airplane performance monitors, or icing conditions detectors may be installed to alert the flight crew to follow AFM procedures when the aircraft is accreting ice or when icing conditions are being experienced.

ADs have been issued requiring the activation of wing deicing boots on regional air transports at the first detection of airframe ice or detection of icing conditions by ice detectors. The ADs also stated that the deicing boots be cycled once the aircraft has exited the conditions. This is a fundamental shift from previous practices, where flight crews would cycle the boots when a certain level of ice was observed to avoid deicing boot ice bridging. In-flight icing accident investigations have shown that flight crews have lost control of the aircraft while judging whether sufficient ice has accreted for activation of the deicing boots. Wind tunnel and flight test results have indicated that ice remaining on modern deicing boots (that operate at higher pressures than earlier designs) after the boots have been activated at the first detection of airframe ice will be shed during subsequent cycling of the boots. Activation of the deicing boots ensures that the ice protection system is used during icing conditions and that deicing boot surface roughness due to ice accretion is held to a minimum.

The appropriate manual should describe the expected icing cues and the flight-crew procedure associated with observing the cues, including when the IPS should be activated, in accordance with 14 CFR parts 23, 25, 27, and 29 §§ .1583 and .1585 and 14 CFR parts 23, 27, and 29 § .1559. The appropriate procedures should be included in the AFM. Emergency or abnormal procedures—including procedures to be followed when IPSs fail or if warning or monitor alerts occur—should be provided. For fluid anti-ice/deicing systems, information and methods for determining remaining flight operation time should be provided.

H.2 References

H1. "**Aircraft Icing Handbook,**" FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA Technical Center, Atlantic City, NJ 08405.

H2 "Calibration and Acceptance of Icing Wind Tunnels," SAE ARP5905.

H3. FAA Technical Report ADS-4, "Engineering Summary of Airframe Icing Technical Data."

H4. Report No. FAA-RD-77-76, "Engineering Summary of Powerplant Icing Technical Data."

H5. NACA Technical Note 1855 (1949), "Recommended Values of Meteorological Factors To Be Considered in the Design of Aircraft Ice-Prevention Equipment," NASA Ames Research Center, Moffett Field, California 94035.

H6. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

H7. **"Airborne Icing Tankers,"** SAE ARP5904.

H8. "Rotor Blade Electrothermal Ice Protection Design Considerations," SAE AIR1667A, pp. 13-24.

APPENDIX I. DROPLET IMPINGEMENT AND WATER CATCH.

I.1 Droplet Impingement and Water Catch

Demonstrating compliance with the airframe, engine induction system, propeller, windshields, and air data system sensor surfaces ice protection requirements, as discussed in section 6 – Ice Protection Requirements, requires determining which aircraft surfaces will accrete ice, the extent of surface protection, and the energy needed to protect the surface from icing. The applicant should supply an impingement analysis to substantiate the extent of the IPS. Guidance for developing such an analysis can be found in the FAA Icing Handbook [I1].

Information needed for determining the chordwise extent of most IPSs includes droplet impingement limits and the related water catch. The location of the supercooled water droplet impingement limits and the resulting water catch are functions of many parameters, including the aircraft configuration, aircraft attitude, local flow angularity, local airspeed and Reynolds number, droplet sizes (mass), catch efficiency, exposure time, and the LWC of the atmosphere. Studies should be performed for all phases of flight and for the associated aircraft configurations in order to determine the chordwise extent of droplet impingement on the surface and the required protection to prevent or remove ice accretion from the surface. Safe operation of the aircraft in icing conditions for the configurations and phases of flight used to define the IPS's coverage should be demonstrated. Also, the configurations that are associated with different phases of flight should be stated in the aircraft's AFM to avoid use of configurations for which the IPS was not designed, and for which safe flight in icing conditions has not been demonstrated, such as only using the cruise configuration for holding in icing conditions.

Surface moisture at and below the freezing point is required for ice to accrete. Some surface leading edges, such as antennae, antennae fairing, and air data probe and vent masts may be located in "shadow" areas in which the cloud drops (in a certain size range), borne by the freestream airflow, do not impinge. The surfaces may be shielded from impingement of the cloud drops for a variety of reasons. They could be in the shadow of forward airframe structure or the cloud drops, especially the smaller cloud drops, could escape impingement on the surface because of the direction of stream airflow. There has even been a documented case where drops in an intermediate size range did not impinge on a fuselage-mounted ice detector while smaller and larger droplets did impinge [I2]. Also, the splashing and bouncing of cloud drops as the drops impinge on the surface and subsequent ice shapes will influence ice accretion. To a lesser degree, larger cloud drops may disintegrate as they traverse regions of high shear stress resulting from changes in the free-stream velocity. Some conditions may result in runback ice accumulations aft of the protected surfaces. Runback ice accumulations are formed either through partial evaporation (by design in a running wet system) or through aerodynamic heating at static temperatures slightly below freezing. This aerodynamic heating can result in a freezing fraction of less than one with water running aft of protected surfaces and forming runback accumulations.

Although other analytical methods exist to determine the droplet impingement limits on airfoils, computer codes are commonly used. These codes are used to calculate not only the impingement area and limits, but also the water mass flux of the body surface, the local water catch efficiency (β), and the total water catch efficiency (E). The codes also provide useful information relative to whether a specific aircraft component will be exposed to atmospheric moisture and, subsequently, ice accretion. For conditions where the airflow is not separated from the surface, these tools offer the advantages of accurately determining local airflow angularities and velocities, the effects of the droplet mass and aerodynamics, and the impingement for a droplet spectrum (rather than a single droplet size). For conditions where the airflow is highly turbulent or separated, Navier-Stokes CFD codes may be necessary. For the configuration being evaluated, experimental substantiation in the form of wind tunnel, natural icing, or tanker data should be provided to validate the computed flow field and droplet impingement.

Justification for using a computer code to determine droplet impingement information should be provided. SAE ARP5903 [I3] provides useful information relative to available droplet impingement codes, their common use, limitations, software verification, validation, and code administration. Conformance with SAE ARP5903 should be considered when judging the acceptability of droplet impingement analyses performed using computer codes.

Empirical evaluations have determined that two-dimensional impingement codes may be acceptably accurate when properly applied to simple, planar configurations for droplet sizes within 14 CFR parts 25 and 29 Appendix C. Use of two-dimensional impingement codes for impingement limit analyses of swept wings and stabilizers typically are accomplished by determining the impingement limits as suggested in [I3] at various stations across the surface span. At the angle-of-attack (AOA) of interest, airfoil sections and pressure distributions are determined by following the longitudinal airflow direction over finite wing or stabilizer lifting surfaces. (Rather than tracking the streamlines across the lifting surface, some manufacturers have approximated the streamline airfoil by using sections that are either normal to the surface's leading edge, normal to the surface's quarter-chord, or normal to the surface's leading edge to the quarter-chord and then streamwise aft.) This wing sectional information may be determined empirically or by using CFD codes. In the absence of separated flow, computer codes that solve the potential flow and Euler equations may be used. The two-dimensional droplet impingement code is then used to determine the impingement limits when the two-dimensional AOA is adjusted to reproduce the finite surface's pressure distribution at the span station of interest. For straight wings and stabilizers, streamwise sections are used, along with the finite wing section pressures to determine the appropriate AOA used with the two-dimensional impingement analysis code.

Empirical validation of impingement codes for configurations where three-dimensional flow fields may be expected (e.g., wing tips, highly swept wings, bodies of revolution, fairings, junctures of bodies, etc.) is limited.

Three-dimensional codes are available to perform impingement and ice shape prediction of various three-dimensional components on airplanes. However, three-dimensional analyses can be very costly in terms of both time and resources, sometimes requiring up to 6 weeks to complete computer calculations for a single configuration. Less costly two-dimensional methods have been used to estimate droplet impingement and ice shapes for various symmetrical aircraft components. This is done using the center-line profile of each symmetrical component. Examples of symmetrical components include radomes, wing mounted fuel tanks, antenna fairings that form symmetric bulges in the fuselage, and light fairings.

Use of two-dimensional codes for such analyses do not address three-dimensional flow conditions (such as cross-flow velocity vectors) that affect the droplet trajectory and impingement, and three-dimensional codes, depending on their sophistication, may not fully account for cross-flow effects. When using two-dimensional codes in this manner, the effects of nonzero pitch and yaw angles of attack should be accounted for. Applicants should provide justification for the use of droplet impingement and ice shape prediction codes in the form of an analysis that shows why the three-dimensional flow may be ignored and how the effects of nonzero angles of attack are accounted for. Additionally, the applicant should validate the acceptability of droplet impingement and ice shape prediction codes. This validation may include one or more of the following:

1. Icing wind tunnel results
2. Icing tanker results
3. Flight in natural icing conditions results
4. Similarity to other airplanes that have validation data from one of the first 3 validation methods.

Note: The use of two-dimensional impingement codes on swept-wing airplanes is discussed in [I3].

The applicant should justify the droplet size or droplet distribution used to determine the impingement limits on the various surfaces analyzed. Guidance provided by an earlier edition of this Advisory Circular stated that a MED drop of 50 μm had been successfully used to determine impingement limits and that an MED drop of 20 μm had been successfully used to determine water catch rate. FAA Technical Report DOT/FAA/CT-88/8-1 [I1] states that for design purposes, a drop size of 40 μm is often used for determining impingement limits. (However, the largest droplet size within Appendix C will determine the maximum impingement limits. The spectrum of atmospheric cloud water drops is highly variable, and since the MED or MVD is the median drop diameter, water drops having larger diameters than the MED or MVD exist in the droplet spectrum. The Langmuir distribution, Table I-1, is commonly used to define the spectrum of cloud drops [I4]. Since larger droplets than the MVD exist, the Langmuir D distribution has been typically used to determine the impingement limits. However, consideration should be given to use of a droplet distribution similar to the Langmuir E distribution, which is most conservative relative to extreme droplet size, with mean volumetric drop diameters of 50 μm when determining impingement limits.) Failure to consider droplets larger than the mean diameter and water impingement below a selected local water catch efficiency (β), such as 0.10, for determining the extent of the protection surfaces coverage may result in ignoring the accretion of thin, rough ice that may cause adverse aerodynamic effects.

Table I-1. Langmuir Distributions

Fractional Liquid Water Content in Each Size Group ~ %	**Langmuir Distribution ~ (Drop Diameter)/Median Drop Diameter**				
	A	B	C	D	E
5	1.00	0.56	0.42	0.31	0.23
10	1.00	0.72	0.61	0.52	0.44
20	1.00	0.84	0.77	0.71	0.65
30	1.00	1.00	1.00	1.00	1.00
20	1.00	1.17	1.26	1.37	1.48
10	1.00	1.32	1.51	1.74	2.00
5	1.00	1.49	1.81	2.22	2.71

Justification should be provided when selecting a local water catch efficiency other than zero for the impingement limits and when choosing not to consider the drop spectrum around a median diameter of 50 μm for determining the chordwise extent of the ice protection surface.

Each ice protected surface should be analyzed for different droplet sizes in order to find the droplet diameter associated with the largest water mass, one factor that may establish the maximum heat requirements for thermal anti-icing IPSs. (See the preceding discussion relative to the use of median droplet diameter or droplet distributions around a median droplet size.) Consideration of other drop diameters may be appropriate when other IPS design requirements are addressed.

Droplet impingement information can also be obtained empirically, using natural icing conditions flight tests, icing wind tunnels, and/or icing tankers. These methods may provide information on ice accretion limits, which should approximate droplet impingement limits in rime conditions but may differ substantially in glaze conditions. These data may be used to validate results obtained from code-derived droplet impingement limits.

During natural icing flight tests to determine icing limits, the icing cloud characteristics (including LWC, temperature, droplet size), airplane airspeed, angle of attack, and altitude should be measured. Sufficient information should be obtained to ensure that demonstrated icing limits address the droplet impingement issues and the phases of flight and associated airplane configurations being approved for flight in icing conditions.

Icing wind tunnels are also used to obtain droplet impingement information, either by determining icing limits or impingement limits through the used of dyed water and blotter paper attached to the model surface of interest. (Techniques have been developed to calibrate water catch with the color intensity of the captured dyed water.) When feasible, icing wind tunnels are useful for determining droplet information for full-scale, three-dimensional configurations. Use of scale models for impingement analysis should be examined since effective impingement scaling requires the matching of the modified icing cloud water droplet inertia parameter, K_0. See Appendix R - Ice Shapes for a detailed discussion on using wind tunnel scaled models to determine ice shapes.

Acceptability of the use of scale models for impingement analysis may be judged, allowing for the repeatability of icing wind tunnel ice shapes, by correlating ice shapes for models of different scale (the ice shapes being indicative of the impinging flow icing limits and water catch flux). This approach is more appropriate with rime ice accretions.

Conformance with SAE ARP5905 [I5] should be considered when judging the acceptability of icing tunnel droplet impingement investigations.

Icing tankers may also be used to obtain droplet impingement limits even though the droplet MVDs may exceed 50 μm. Tanker tests permit testing of full-scale configurations, but are limited by the spray array's plume size and ability to match Appendix C droplet sizes and LWC, especially at an MVD of 50 μm. However, droplet impingement limits determined with MVDs exceeding 50 μm under rime icing conditions have been considered to provide conservative estimates of the impingement limits for some applications. Conservative use of icing tanker investigations should be justified by the applicants. Applicants should demonstrate that the icing tanker, associated instrumentation, and icing cloud plume are calibrated. Also, the applicant should demonstrate that the impingement evaluation was performed using commonly accepted practices. Conformance with SAE ARP5904 [I6] should be considered when judging the acceptability of icing tanker droplet impingement investigations.

The wing's lower surface impingement limits suggest that the ice protection would need to extend far aft in order to encompass the entire impingement region. Structural (front spar location) and IPS energy considerations typically determine the extent of the IPS on the wing's lower surface. Airplane drag is usually the most significant aerodynamic effect of lower surface ice accretion roughness aft of the airflow's stagnation point (line) at airplane stall. Aircraft manufacturers will typically accept the drag penalty on performance rather than extending the IPS too far aft on the wing's lower surface. The aerodynamic effects of ice accretion aft of the selected lower surface aft ice protection limit should be considered when demonstrating safe flight of the aircraft in icing conditions. Typically, simulated ice shapes are used for this purpose. Since the aircraft horizontal stabilizer may lift in both directions, the design philosophy used for the ice protection on the wing may not be appropriate for the horizontal stabilizer. These considerations reflect the use of engineering judgment and experience in design of IPSs. Section 1419 of 14 CFR parts 23, 25, 27, and 29 requires that safe operation of the aircraft be demonstrated in natural icing conditions with the proposed IPS, supplemented by analyses and laboratory tests as necessary, to verify adequacy of the IPSs for icing conditions throughout the required icing environment.

I.2 References

I1. "**Aircraft Icing Handbook,**" FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA Technical Center, Atlantic City, NJ 08405.

I2. "Certification and Integration Aspects of a Primary Ice Detection System," D. Jackson, D. Owens, D. Cronin, and J. Severson, paper no. AIAA-2001-0398, AIAA 39th Aerospace Sciences Meeting, Jan. 8-11, 2001. Reprints available from American Institute of Aeronautics and Astronautics, Reston, VA 20191-4344.

I3. **"Ice Accretion and Droplet Impingement Codes,"** SAE ARP5903.

I4. **Mathematical Investigation of Water Droplet Trajectories**, *The Collected Works of Irving Langmuir,* New York, *Published by Pergamon Press* [c 1960-62], p. 348-393.

I5. **"Calibration and Acceptance of Icing Wind Tunnels,"** SAE ARP5905.

I6. "**Airborne Icing Tankers**," SAE ARP5904.

APPENDIX J. PROPELLER ICE PROTECTION.

J.1 Propeller Ice Protection.

When the airplane's powerplant installation includes propellers, ice protection provisions of the propellers must meet the applicable requirements of 14 CFR §§ 23.929, 23.1419, 23.1301, 23.1309; 25.929, 25.1091, 25.1419, 25.1301, and 25.1309. To comply with these requirements, each installed propeller must provide provisions to prevent or eliminate hazardous ice accretion within icing conditions for which airplane certification is requested. With the ice protection provisions installed, the propeller assembly must meet the requirements of 14 CFR part 35, which are primarily structural. The propeller IPS should prevent or remove hazardous ice accumulation that could jeopardize engine performance and enable satisfactory functioning without appreciable loss of thrust. In showing compliance with propeller ice protection requirements, factors that should be considered include:

- Airplane performance loss
- Thrust requirements for airplane handling qualities evaluations, such as when demonstrating stall warning and stall recovery
- Vibrations
- Engine ice ingestion
- Airframe damage from ice shed from the propeller
- Propeller structural behavior (integrity) resulting from functioning or failure of the propeller IPS
- Power requirements for ice protection
- Margins for operation in icing conditions which may exceed certification requirements

Compliance with regulatory requirements should be based on either analyses and/or laboratory tests and on flight tests in measured natural icing conditions, as stated in 14 CFR parts 23, 25, 27, and 29 § 1419. Analyses used to support compliance with icing requirements should be verified by test to demonstrate acceptable effectiveness in predicting the particular IPS feature or function.

Analyses should be performed to establish:

- The most critical flight icing condition
- The required zones of ice protection
- The use of and operational modes for electrothermal ice protection. Factors to include in this evaluation are:
  - Heat transfer characteristics
  - Power requirements, assuming an atmospheric temperature of -30°C
  - Intercycle intervals and critical ice shapes, if required, and the effects of the intercycle ice
  - Runback ice and its effects

- Deicer timer cycle

- AFM limits for fluid systems, to prevent exhaustion of the fluid prior to exiting the icing conditions

- The maximum size and trajectory of the ice that is shed from the propeller (such as, propeller inter-cycle ice) to ensure that the energy of the shed ice does not damage the airframe structure, resulting in unsafe conditions

- The integrity of the propeller and the propeller IPS when subjected to high temperatures due to hot weather operation or failure of the thermal regulator

Other concerns include:

- The effect of deicer boot installation on the propeller blade

- The effect of the slip ring or equivalent accessories on the hub structural integrity

- Blade surface temperatures

- Voltage and current transmission losses from the airplane to the deicer boot

- Timer and other control system component reliability

- Spinner ice accumulation

- Brush block/slip ring hydroplaning when exposed to moisture

- Reliability of wiring, brush blocks, slip rings, and other components.

The propeller must operate throughout the flight power range of the engine (including idle), within the limitations established for the airplane without penalty to the operation of the engine. There must be no loss of thrust throughout the full rotational speed and pitch range expected during icing conditions that would result in a hazard to the airplane in terms of airplane performance and handling qualities, or structural damage from propeller ice shedding. This capability must be demonstrated within icing conditions specified by 14 CFR part 25, Appendix C. This capability must be demonstrated in flight test by targeting the predicted critical icing conditions within 14 CFR part 25, Appendix C.

Propeller ice accretion with an operative propeller IPS in icing conditions that temporarily exceed 14 CFR part 25, Appendix C icing conditions may become hazardous and therefore should be considered. This is demonstrated in Figure J-1, where a coating of ice along the leading edge of the blade can be observed on the propeller blades on top of and beyond the protected area of the blade. Propeller thrust may be severely affected by this type of ice accretion. In addition, icing tunnel testing and flight testing of propellers runback have resulted in propeller performance losses of up to 20 percent. Airframe and propeller ice accretion in conditions that temporarily exceed 14 CFR part 25, Appendix C icing conditions may impact the ability of the airplane to accelerate out of stall warning and stall entry events by increasing propeller power.

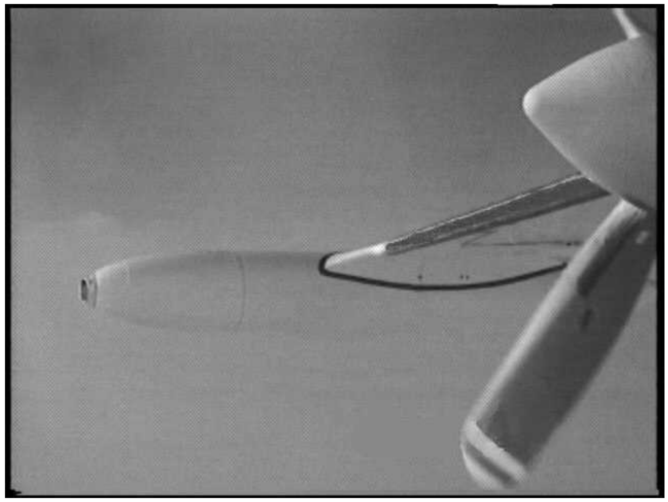


Figure J-1 Propeller ice accretion during an SLD encounter with the propeller ice protection system operating [J1].

While testing, any significant vibrations should be investigated. Consideration should be given to the maximum temperatures to which a composite propeller blade may be subjected during operation of the IPS, including inadvertent operation on the ground during hot day conditions or during dry air flight. For electrically-protected propellers, the system current, brush block voltage (between each input brush and the ground brush), and system duty cycles should be monitored during tests to ensure that proper power is applied to the deicer protection surfaces. The system should also be monitored during flight in rain to ensure proper operation.

J.2 References

J1. **"SLD Encounter, MU-2B-60, March 5, 2000, ABQ-ABQ, Alt = 16,100 ft, IOAT = -7C."**

APPENDIX K. ICE AND ICING CONDITIONS DETECTION.

K.1 Ice and Icing Conditions Detection

Icing instrumentation systems may provide information to the flight crew and/or aircraft systems concerning inflight icing. Components of the system may be intrusive or non-intrusive to the airflow. The system may be directly or indirectly sensitive to the physical phenomena of inflight icing. Some possible icing instrumentation technologies include: latent heat of fusion, changes in electrical fields, changes in the natural frequency of vibrating components, visual cues, ultrasonic waves, optical methods such as infrared or laser cameras, friction between a rotating cylinder and scraper, etc. See Chapter 2, Section 1, of [K1] and [K2] for additional information on ice detector technologies and ice detectors.

A FIDS may include a processing unit to perform signal processing, sensor monitoring, data communication, or other functions. The processing unit may either be integrated with or separate from the sensor(s). A FIDS may be connected to a device for providing information to the cockpit crew. In addition, the FIDS may communicate with other on-board equipment or systems such as the IPS actuation logic and/or the stall protection system.

A FIDS that detects ice accretion will signal the flight crew and/or systems about the presence of ice accretions on monitored aircraft surfaces. It may also inform the crew or a system about ice thickness, ice accretion rate, LWC, cloud droplet size, and/or accretion location. Since the FIDS probe is attached to the aircraft, the FIDS will detect ice accretion occurring at the aircraft's local air velocity provided it is located outside of the boundary layer flow. Because of dynamic heating of the local airflow that varies with airspeed, ice may not accrete on the ice detector, engine induction system inlet or engine components, or on other aircraft surfaces at the static atmospheric temperatures of 14 CFR parts 25 and 29 Appendix C. Initial ice accretion may vary on the aircraft, since local airspeeds are a function of local surface curvature, local AOA, freestream airspeed, and other factors. A FIDS that detects ice accretion may be located on or may be remote from the aircraft lifting surfaces or other monitored surfaces such as engine inlets. The lifting surfaces may not be the reference surface, but ice accretion on the lifting surface must be correlated to ice on the reference surface such that safe flight required by 14 CFR parts 23, 25, 27, and 29 § 1419 is ensured.

A FIDS that detects icing conditions provides information to the flight crew and/or aircraft systems concerning atmospheric icing conditions. Components of the system may be intrusive or non-intrusive to the airflow. The output of such a FIDS informs the flight crew and/or aircraft systems about the presence of atmospheric conditions that are conducive to the accretion of ice on aircraft surfaces. A FIDS that detects icing conditions, for example by sensing a temperature threshold and the presence of moisture, is not necessarily sensitive to the presence of airframe ice accretions.

FIDS may be divided into two types:

- Advisory flight ice detector system (AFIDS)
- Primary flight ice detector system (PFIDS)

K.1.1 AFIDS

An AFIDS provides an advisory annunciation of the presence of ice accretion or icing conditions, but is not relied on as the sole, or primary, means of detection. The flight crew is responsible for monitoring the icing conditions using a primary method as directed in the AFM. Typical primary methods include monitoring of:

- AFIDS

- Total air temperature
- Visible moisture criteria
- Visible ice accretion

Manual activation of the aircraft's IPS(s) by the flight crew is necessary when the condition of the primary method is met. Manual activation of the IPS may be integrated with other systems (e.g., a stall protection schedule that adjusts to provide adequate stall margin for flight in icing conditions). The AFIDS provides information to advise the cockpit crew of the presence of ice accretion or icing conditions, but it can only be used in conjunction with other primary methods to determine the need for operating the anti-icing or deicing system.

K.1.2 PFIDS

A PFIDS annunciates the presence of ice accretions or icing conditions to the flight crew and may also provide information to other aircraft systems. Primary flight ice detection systems, when used in conjunction with the approved AFM procedures, can be relied upon as the sole means of detecting ice accretion or icing conditions. PFIDS can be classified as primary automatic or primary manual. In a primary automatic system, the FIDS automatically activates airframe IPSs. It may activate the propulsion system IPS, and increment the stall speed warning/stick pusher schedule, as necessary, to ensure adequate stall margin for flight in icing conditions. Activation of the propulsion system IPS may occur earlier than those of the airframe. In a primary manual system, the cockpit crew activates the IPSs based on the PFIDS annunciation. Manual activation of the IPS may increment the stall protection schedule to ensure adequate stall margin for flight in icing conditions. Note that if automatic activation of the IPS is overridden by manual activation, the incremented stall protection system schedule should be implemented. A PFIDS must be self-monitoring and must provide an indication to the flight crew in compliance with 14 CFR parts 23, 25, and 29 § .1309 and 14 CFR part 25 § .1419(c) when there is a fault in any ice detection channel. The pilot can then take the corrective actions prescribed in the AFM to ensure continued safe flight and landing.

K.2 Ice Detector Sensor Characteristics

To ensure that the ice detection system is adequate, the aircraft manufacturer needs to have an understanding of the characteristics of the ice or icing conditions detector, its limitations, and its capabilities. This evaluation should include understanding sensor ice detection technology, limitations, the atmospheric conditions and aircraft flight regimes in which the sensor will detect ice or icing conditions, ice accretion rate on the sensor, sensor ice collection efficiency, the time interval required to detect ice or icing conditions, the deicing cycle of the ice detector sensor, and tendencies of the system to become saturated under certain icing conditions.

K.2.1 Freezing Fraction (*n*) Considerations

Airplanes have accreted both engine inlet and wing ice without indication by ice detectors. The ice detectors had been properly located on these airplanes, but were operating in low freezing fraction conditions. Ice accretion on airplane surfaces without indication by ice detectors has also been demonstrated in an icing wind tunnel. Accretion of ice on protected airplane surfaces and components without detection by a PFIDS is an unsafe condition. The applicant should perform analyses and tests to determine the conditions that may result in the ice detector not performing its intended function. The applicant should then redesign the ice detector system to ensure detection prior to ice accretion on the airplane, engine induction system, and the engine, or provide procedures that will ensure continued safe flight and landing. Such procedures may include instruction in the AFM to actuate the IPS manually under specific temperatures and visible moisture. The AFM procedure should be considered as the last resort. Note, relocating the ice detector may not be a feasible solution since the local surface temperature of the airplane components that are accreting ice is affected by the local boundary layer conditions.

The ability or response time for an ice detector to sense the presence of ice varies with the sensor's technology. For accretion-based ice detectors, as the local temperature of the ice detector sensor approaches 0° C, water droplets may freeze or remain in the liquid phases, delaying the accretion and detection of ice. However, surfaces with higher local velocities elsewhere on the aircraft, such as on the inlet of a turbine engine under some operating conditions that affect inlet air velocities and on lifting surfaces with areas of high local velocities, may exhibit lower local temperatures and higher rates of ice accretion. . Consideration of the effects of freezing fractions (the amount of water that freezes on a surface divided by the total amount of water that impacts the surface) being less than one on the ice detector sensor is important when incorporating a FIDS or an ice evidence probe on an airplane.

With the local temperature well below the freezing point, icing cloud supercooled water droplets freeze on contact with ice detector sensor surfaces, resulting in predictable and acceptable ice detection capability and response times. When the ice detector sensor's freezing fraction is < 1, the rate of ice accretion on the sensor decreases and the time required for the detector to detect the presence of ice on the sensor and provide an indication of ice accretion may increase significantly.

The TC applicant should show that the ice detector annunciates the presence of icing for all icing conditions for which the airframe and engine induction system accrete unsafe quantities of ice. This requires showing that the ice accretion rate (W) of the ice detector sensor is higher than for any other part of the aircraft for ambient icing conditions required.

A means of demonstrating acceptable ice detector ice detection response time is provided in Reference K3. The paper shows that factors that affect ice accretion rate, W, are E, LWC, V, and n. Each of these factors should be evaluated to show that the detector ice accretion rate is sufficiently greater than the rate for the wing or engine and that detection and IPS actuation will always occur prior to a hazardous accretion of ice. Currently there are icing codes that predict the icing characteristics for freezing fractions < 1. But many of these codes do not account for changes in E or n as a function of ice buildup. Also, the modeling of surface temperature resulting from boundary layer effects and surface cooling from the impinging supercooled cloud drop may be approximate. The complete substantiation package may also require evaluation of the ice detector installation in a wind tunnel. Since the temperature range of interest may be within approximately 5 °F of the ambient freezing temperature, the icing wind tunnel should have a sufficiently uniform test volume and be in calibration to investigate this phenomena [K4].

K.2.2 Droplet Splashing, Runback, and Shedding

Other phenomena that should be evaluated for ice accretion detectors are water droplet splashing, runback, and shedding. Splashing occurs when the impact of a large droplet on the icing sensor or aircraft surface causes the droplet to break up and either depart the surface in the adjacent airstream or redeposit on another area on the aircraft. Impinging droplets that do not immediately freeze on contact with the sensor surface may result in runback icing. The droplet remains on the surface in the liquid state and subsequently coalesces with other droplets, forming a larger droplet that is forced aft on the sensor surface by the local airflow shear force Droplets can run back in benign rivulets or can form a ridge of ice aft of the ice protection equipment. Shedding occurs when a liquid droplet on a surface gets larger, due to coalescence with smaller droplets, and is sheared from the sensor surface by the local airflow before freezing. Runback and shedding are associated with a freezing fraction < 1 and generally become more pronounced as the freezing fraction approaches zero. Splashing should be evaluated for all conditions when the freezing fraction is < 1.

Splashing or shedding may occur at the detector but not on the larger airplane surfaces, and may result in delayed ice detection by the ice detector. Failure or delay in the ice detector's detection of ice could result in hazardous ice buildup on the lifting surfaces, such as on the wing or horizontal stabilizer, or on the engine induction system inlets. The applicant should substantiate that the airplane is capable of safe flight in all icing conditions. Some impingement computer codes include provisions for calculating the quantity of runback icing, but do not address the characteristics of the runback ice nor water mass loss due to splashing or shedding. However, the runback capability of these codes has not been thoroughly validated using wind tunnel or flight tests. Therefore, icing wind tunnel tests should be used to investigate the splashing, blow-off, and runback characteristics of the ice detector system (see K.3.1 – Freezing Fraction (n) Considerations).

K.3 Installation Location

The ice detector should be installed at a location that ensures safe flight by detection of icing prior to a hazardous build up of ice on the airframe or engine inlets. After the ice detector is mounted, it is calibrated to annunciate icing prior to unsafe ice accretion on monitored surfaces. The ice detector should be located on the airframe surface where the sensor is adequately exposed to the icing environment. Proper location of the ice detector requires flow field and boundary-layer thickness analyses of candidate sensor locations. The analysis should be performed at AOAs, airspeeds, sideslip angles, and with configurations approved for flight in icing. Local flow conditions and boundary-layer conditions may shield the sensor from adequate sampling of the icing environment. Also, local flow conditions may:

- alter the freestream icing characteristics by preventing droplets of certain sizes from impinging on the ice detector sensor (shielding or shadowing the sensor location by carrying off droplets having insufficient momentum to penetrate local flow conditions),

- result in unacceptable airspeeds relative to freestream airspeed and,

- result in unacceptable variation in orientation of the sensor to local flow angularity and airspeed with changes of the airplane's configuration and flight regime.

The applicant should validate the location of the ice detector. Typically, full configuration (three-dimensional) CFD analyses, with viscosity capability to assess boundary-layer thickness, are performed to address these considerations. (Reference [K3] provides useful information relative to proper installation location for certification of a magnetostrictive technology PFIDS.) If analysis reveals that the candidate ice detector locations are not influenced by the wing or changes in the wing configuration, or other aircraft components, the CFD analysis may be confined to the aircraft component of interest. Care should be given to the effects of the propulsion system, such as propeller effects and flow field variations that may occur with turbine-powered aircraft if the detector is located in and near the engines. Wind tunnel, tanker, and natural icing conditions tests may be required to verify these analyses.

There have been instances where pilots have detected ice prior to the PFIDS alerting them. This can occur due to poor probe placement (as well as other reasons like other components on the airplane having higher collection efficiency). Poor sensor placement can cause a delay or failure of an ice detection system to detect ice accretion or icing conditions and result in a hazardous condition. Reference [K3] documents that improper placement of an ice detector sensor can result in the detection of large droplets and small droplets but that medium sized droplets can be aerodynamically shadowed. This result is counter-intuitive and shows that thorough analysis and testing are required to ensure appropriate placement of PFIDS sensors on an airframe and selection of PFID sensors that will detect all droplet sizes. Helicopters may require a system to induce airflow across PFIDS sensors during low speed flight. Similar analyses and testing will be required to ensure that ice accretion or icing conditions are detected prior to an unsafe condition occurring. CFD software is the only practical means of performing the placement analysis. Validation of the analyses is typically done during natural icing flights tests. Correlation of the ice detector's detection of icing relative to ice accretion on the monitored surfaces should be verified by measured natural icing flight tests.

In addition to the appropriate placement of the FIDS' sensors for ice detection, the airframe manufacturer needs to show that ice accretions occurring forward of the sensor, such as on the radome, do not interfere with the airflow ice sensing, and that shed ice will not damage the detectors. Also, other probes located forward of the ice detector should not interfere with the proper functioning of the ice detector with changes in the airplane configuration and flight regime.

K.4 System Considerations

Previous certifications have considered that the top-level system requirement for a PFIDS is that the unannunciated failure of the system to detect ice or icing conditions be extremely improbable (not expected to occur in the life of the fleet) which coincides with an assumed hazard level of catastrophic. However, reduced hazard levels for specific aircraft may be considered in determining requirements for new PFIDS certifications relative to 14 CFR parts 23, 25, 27, and 29 § .1309 if sufficient evidence is available of the reduced hazard. Early concurrence from appropriate certification authorities should be sought prior to using reduced hazard levels in designing a PFIDS. An assessment of airframe PFIDS indicates that the following items need to be reviewed in any system that is intended as the prime means of alerting the flight crew to icing conditions or automatically operating the deicing/anti-icing systems:

1. There should be at least a dual detector system each having an independent failure monitoring system.

2. The effectiveness of the PFIDS must be demonstrated during the icing flight tests of the applicable parts of 14 CFR parts 23, 25, 27, and 29 §§ .1093 and .1419, and should have the following minimum capabilities:

    a. The threshold accretion, or icing condition level, chosen to activate the detector and annunciation system and ensuing ice accretion as the IPS becomes fully effective must ensure safe flight of the aircraft. This is done by ensuring that the pre-activation ice does not constitute a hazard and that when the accreted ice is shed, there will be no hazardous or unsafe structural or operability damage to the engines and airframe.

    b. The system should not be overly sensitive and produce nuisance alerts or IPS activation. Nuisance alerts (frequent changes from "on" to "off") may induce the pilot to ignore ice detector indications. However, the system must be sensitive enough to readily detect sudden exposure to icing conditions throughout the complete approved regulatory icing envelope.

    c. If overheat of structure (such as engine inlet cowl) can result from the anti-icing/deicing systems being automatically activated by the PFIDS (including due to a false indication) during any operations, then a means must be provided to alert the flight crew to such overheating, directing them to an effective shutdown procedure.

    d. The AFM must address the operational use of the PFIDS and its limitations. The AFM must also give procedures to follow after failure indications.

3. A PFIDS must be designed to be highly reliable to meet the applicable requirements of the 14 CFR parts 23, 25, 27, and 29 §.1309 and 14 CFR parts 25 and 29 § .901c. This means that combinations of system failures that result in undetected ice or icing conditions for the equipped aircraft must be extremely improbable. The requirement is based on the premise that flight crew must be assured that they will be informed when the system has failed, so that they may revert to the conventional method of ice detection upon annunciation of a detected fault (i.e., monitoring of the temperature and visual cues). Consideration for multiple and independent systems, automatic fault monitoring, built-in test equipment (BITE), preflight status tests, etc., may be used to support this high degree of design reliability. Detailed guidance information is provided in ACs 23.1309-1B, 25.1309-1A, 27-1B, 29-2C, and 33-2B.

K.5 Certification of Ice Detectors

K.5.1 Certification of an AFIDS

Ice detector equipment, when used to obtain approval for flight in icing conditions, is integral to the aircraft's IPS and must meet the airframe, engine, engine induction system, propeller, windshields, and air data system sensor surfaces ice protection requirements discussed in Section 6 – Ice Protection Requirements. Advisory flight ice detection systems should detect ice within the icing environment limited by the aircraft's flight envelope or defined by 14 CFR parts 25 and 29 Appendix C, as applicable, for the aircraft configurations and associated airspeeds requested for approval. The AFIDS, in conjunction with the primary methods (e.g. temperature and moisture, visible ice accretion), should advise the pilot to initiate operation of the deicing or anti-icing system using AFM procedures prior to a hazardous build up of ice on the airframe or unsafe flight.

The applicant should substantiate the ice contamination of the aircraft at the time the IPS becomes effective, following detection of icing. This contamination should account for reasonable time delays in the activation and effectiveness of the deicing or anti-icing systems. The applicant should also assess aircraft performance and handling qualities relative to the applicable regulatory definition of safe flight. The AFIDS should be able to perform its intended functions for the applicable aircraft configurations, flight regimes, and icing environment.

To install an AFIDS appropriately on an airplane, analyses similar to those performed on a PFIDS should be performed to understand the characteristics, limitations, and installation of AFIDS sensors. Of concern is that pilots may come to place effectively the same reliance on an AFIDS that would be placed on a PFIDS even though it may not have the same reliability. This underscores the importance of performing these necessary analyses and providing appropriate AFM information to ensure proper functioning and usage of the system.

Approval of the AFIDS should include measured natural icing flight tests to verify analyses and laboratory test results and to verify that the ice detector performs its intended function within the applicable icing environment and for the requested configurations and flight regimes. Laboratory tests may be used to demonstrate the ability of the ice detector to function properly for Appendix C icing conditions not likely to be encountered during natural icing flight tests. An AFIDS should meet certain reliability requirements, if the device is used with other icing cues, to meet the IPS equipment reliability requirements of 14 CFR 25.901(c), 27.901(b)(1), 29.901(c), as well as 14 CFR parts 23, 25, 27, and 29 §§ .1301 and .1309. The probability of encountering icing conditions is considered 1. Detailed equipment reliability guidance information is provided in ACs 23.1309-1C, 25.1309-1A, 27-1B, 29-2C, and 33-2B. Procedures pertaining to the use of the ice detector as part of the IPS should be provided in the appropriate manual, as required by 14 CFR 25.1585(a)(6) and §§ 23.1585, 27.1585, as well as 29.1585.

K.5.2 Certification of a PFIDS

Ice detector equipment, when used to obtain approval for flight in icing conditions, is integral to the aircraft's IPS and must meet the requirements of 14 CFR 25.901(c), 27.901(b)(1), 29.901(c), and 14 CFR parts 23, 25, 27, and 29 §§ .1419, .1301, and .1309 of. A PFIDS must detect ice within the icing environment defined by Appendix C, the icing environment assumed by aircraft components for compliance with applicable regulations, or the aircraft's flight envelope within Appendix C if selected , as applicable, for the aircraft configurations and associated airspeeds requested for approval. An icing condition PFIDS must detect icing conditions as defined by Appendix C or as limited by the aircraft's flight envelope within Appendix C, as applicable. The PFIDS must ensure safe flight by either alerting the pilot to operate the deicing or anti-icing systems using AFM procedures or by automatically activating the deice or anti-ice system prior to a hazardous or unsafe build-up of ice on the airframe, engine components, or engines inlets, as required by applicable safe flight regulations. The PFIDS must be able to perform its intended functions for the aircraft configurations, flight regime, and icing environment required or requested, as applicable. The PFIDS functioning should account for reasonable time delays in the activation and effectiveness of the deicing or anti-icing system and should factor in the effects of residual and intercycle ice if the PFIDS is used as part of an automated deicing system.

The applicant should substantiate the ice contamination of the aircraft at the time the IPS becomes fully effective, following detection of icing by the ice detector. The applicant should also demonstrate that the aircraft's performance and handling qualities as well as the engine's performance and operability comply with the applicable regulatory definitions of safe flight. As part of the ice protection system, approval of the PFIDS must include natural icing flight tests to verify analyses and laboratory test results, as required by 14 CFR parts 23, 25, 27, and 29 § .1419. Approval of the PFIDS must also verify that the ice detector performs its intended function, in order to ensure safe flight within the applicable icing environment and for the requested configurations and flight regimes. Laboratory tests should demonstrate the ability of the ice detector to function properly within the icing conditions associated with the required icing environment and requested flight regimes (airspeed, altitude, Mach number), which may not be encountered during flight tests. Showing the capability and reliability of a PFIDS requires detailed analysis as required by 14 CFR 25.901(c), 27.901(b)(1), 29.901(c), and 14 CFR parts 23, 25, 27, and 29 §§ .1301 and .1309, and should include a thorough understanding of the characteristics of the detection sensors and their relationship to airframe and engine icing. Detailed equipment reliability guidance information is provided in ACs 23.1309-1C, 25.1309-1A, 27-1B, 29-2C, and 33-2B. The probability of encountering icing conditions is considered as 1. Procedures surrounding use of the ice detector as part of the IPS should be provided in the appropriate manual, as required by 14 CFR 23.1585, 25.1585(a)(6), 27.1585, and 29.1585. Several of the analyses and tests that may be required include ice detector sensor characteristic analyses; installation location analyses; freezing fraction analyses; analysis of the effects that splashing, blow-off, and runback may have on the ice accretion detectors' ability to detect ice in a timely manner; and ice detector system reliability analysis. Each of these analyses is discussed above.

K.6 References

K1. "Aircraft Icing Handbook," FAA Technical Report DOT/FAA/CT-88/8-1 (1991), 3 vols., FAA Technical Center, Atlantic City, NJ 08405.

K2. "Minimum Operational Performance Specification for Inflight Icing Detection Systems," SAE AS5498, October 2001.

K3. "**Certification and Integration Aspects of a Primary Ice Detection System,"** D. Jackson, D. Owens, D. Cronin, and J. Severson, paper no. AIAA-2001-0398, AIAA 39th Aerospace Sciences Meeting, Jan. 8-11, 2001. Reprints available from American Institute of Aeronautics and Astronautics, Reston, VA 20191-4344.

K4. **"Calibration and Acceptance of Icing Wind Tunnels,"** SAE ARP5905.

APPENDIX L. INSTRUMENTATION.

L.1 Instrumentation.

Section .1419 of 14 CFR parts 23, 25, 27, and 29 require that icing conditions be measured during flight testing in natural and artificial (simulated) icing conditions. Measurements should characterize the icing conditions relative to parameters useful for understanding the performance and effectiveness of the IPS, to verify the IPS analysis, to understand icing anomalies that may be observed, and to allow extrapolation of the observed IPS performance and effectiveness to other conditions within 14 CFR parts 25 and 29 Appendix C. Parameters selected to define 14 CFR parts 25 and 29 Appendix C were considered those important for the design of thermal ice protection systems (liquid water content, mean drop diameter, temperature, cloud extent, and altitude) and are typically measured during natural and artificial icing flight tests, along with airspeed, to characterize the test icing environment.

Modern flight tests have used hot-wire type probes for LWC measurement, and a laser-based (electro-optical) droplet size spectrometer for counting and sizing cloud droplets [L1, L2].

A research type of icing rate sensor, such as the Rosemount model 871FA, may be used as a component of the instrument suite. Use of the information obtained using the icing rate meter is discussed in Appendix O – Using Icing Rate to Document Icing Exposures.

Ideally, the measurement of all required variables should be recorded continuously with 1-second resolution during the icing encounters. Spot measurements or long distance averages are less desirable.

The older methods of measurement (rotating cylinders for LWC, and coated slides for dropsize analyses) are also less desirable because of their serious limitations. These limitations include measurement errors, spot sampling, and the difficulty of data reduction [L2]. But hot-wire probes and electro-optical devices are often problematical too, and should be calibrated, installed, and operated by an experienced technician. Icing rate meters should be installed at a proper location on the aircraft. (See Appendix K – Ice and Icing Conditions Detection). The data should be analyzed by those who are experienced in using these modern probes using accepted analysis methods, and by those who know how to recognize any subtle errors in the probe performance. If necessary, several commercial enterprises are available to supply this service.

Video cameras with adjustable zoom lenses are desirable for documenting ice accumulations on the wings and other probes or surfaces of interest. A video view of the wingtip area also provides a good qualitative record of the density and continuity of cloud conditions during icing encounters. A cloud that is dense enough to obscure the wingtip on a typical General Aviation airplane will usually be a convective (or intermittent maximum) type of cloud. Stratiform clouds tend to be less dense. Video may also be useful for recording the presence of precipitation that is illuminated by the wingtip strobe lights or landing lights.

L.2 References

L1. "Aircraft Icing Handbook, Volume 1 of 3," FAA Report number DOT/FAA/CT-88/8-1 (1991), FAA Technical Center, Atlantic City International Airport, NJ 08405.

L2. "**Cloud Physics Instruments for Measuring Icing Conditions**", Richard K. Jeck, FAA Technical Report DOT/FAA/AR-02/120 (2003), FAA Technical Center, Atlantic City, NJ 08405.

APPENDIX M.FINDING NATURAL ICING CONDITIONS FOR TEST PURPOSES.

M.1 Background.

Atmospheric icing conditions sufficient for required flight testing may be elusive, especially when aircraft program schedules require that the testing occur during seasons when climatic conditions are not conducive to development of inflight icing conditions. Even during climatic conditions that are conducive to development of inflight icing conditions, the prevailing icing conditions may not be of sufficient intensity to produce adequate aircraft icing to achieve test objectives. The following provides statistical information relative to the occurrence of atmospheric icing conditions and information concerning how to obtain icing conditions forecasts that may facilitate planning for natural icing flight tests.

M.2 Statistical Guidance.

The LWC values graphed in Figures D-1 and D-4 of Appendix D are approximately the 99th percentile values to be expected during random flights in icing conditions. These large values are seldom found in practice, and test flights usually have to settle for much smaller values. The FAA Technical Center has compiled about 28,000 nmi of inflight measurements of cloud water content, droplet sizes, temperatures, and other variables in supercooled clouds over portions of North America, Europe, and the northern oceans to provide better practical statistics on icing conditions. The following paragraphs describe some of the results.

M.2.1 Natural Probabilities for LWC Averages in Stratiform Icing Conditions.

Figure M-1 depicts the statistical probability of finding various average values of LWC as a function of averaging distance in continuous stratiform clouds. The 50 percent curve shows that half of all random icing encounters will yield less than 0.2 g/m^3, depending on the exposure distance, and the 90 percent curve shows that 90 percent of the encounters will contain less than 0.45 g/m^3.

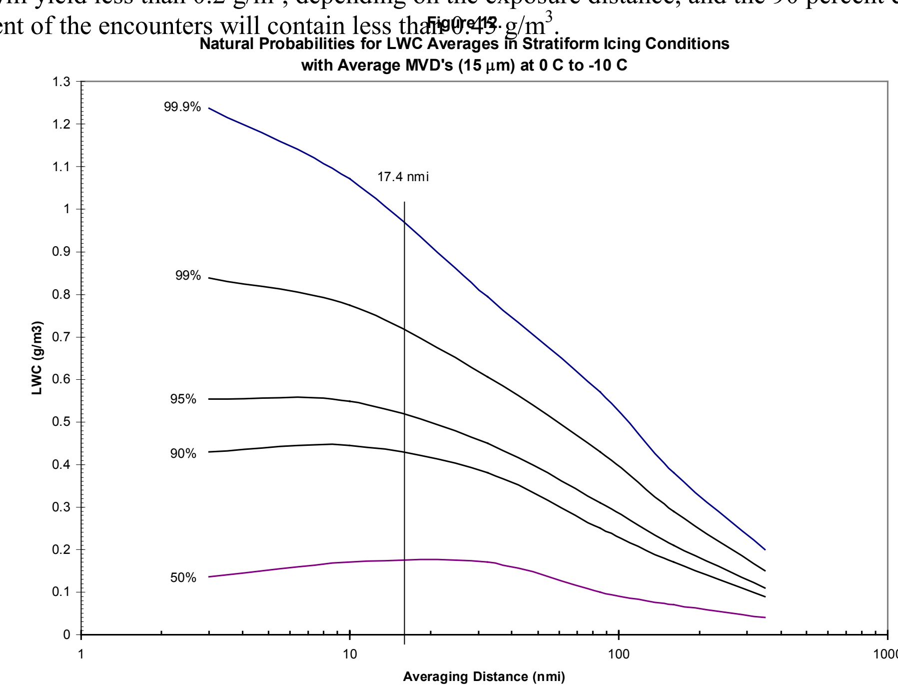


Figure M-1. Natural probabilities for LWC averages in stratiform cloud icing conditions at 32^o F to 14^o F, with an average MVD of 15 µm.

These curves are for typical MVDs of around 15 µm and for flight-level temperatures between 0° C and –10° C. For other MVDs and/or lower temperatures, the LWCs will be even less.

The LWC axis can be converted to icing rate for any particular airframe component or for an icing rate meter, if desired [M1]. Measured LWC averages (or icing rates) can be plotted on Figure M-1 as a useful way to compare the available exposures with nature. Other statistical tables can be found in [M2].

M.2.2 Natural 99 Percent LWC Limits vs. Altitude

Figure M-2 depicts the variation of the 99 percent value of LWC as a function of altitude and exposure distance. For encounters between about 6 nmi and 50 nmi, the largest LWC averages can be expected between 10,000 ft and 15,000 ft AGL. For longer encounters, the largest LWC averages may be found anywhere between 5000 ft and 15,000 ft, with a slight preference for clouds with tops near 5000 ft AGL. Again, the LWC axis can be converted to icing rate, if desired, and measured averages of LWC or icing rate can be plotted to compare with the probable maximum values.

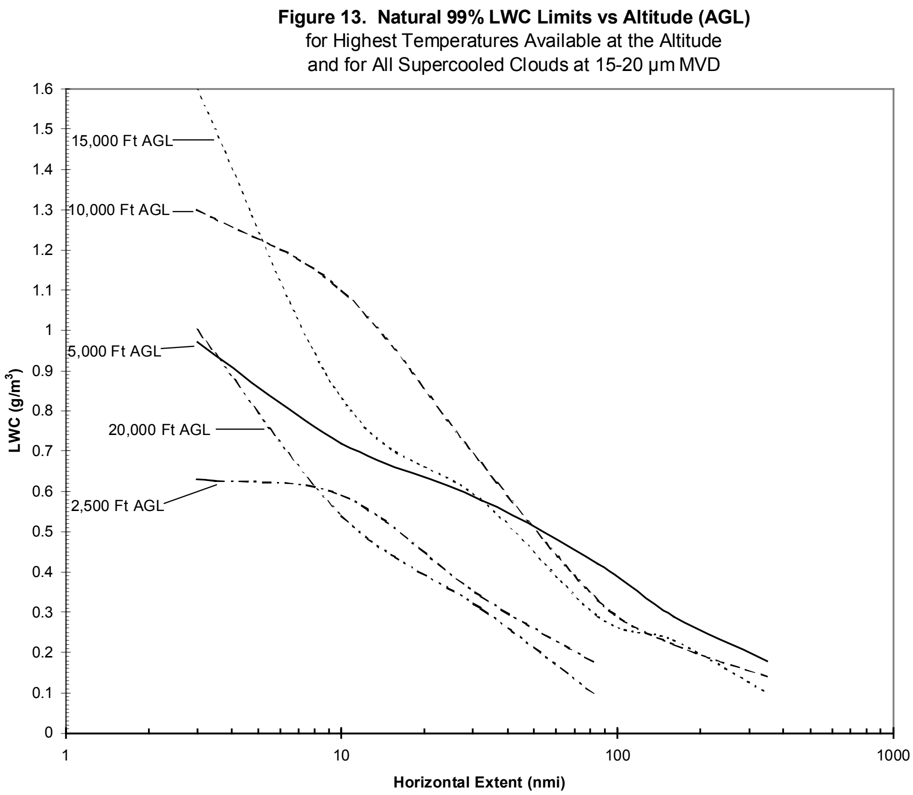


Figure M-2. Natural 99 percent LWC limit envelopes at the highest icing temperatures available at indicated altitude as a function of cloud horizontal extent (for all clouds containing supercooled water drops with MVD = 15-20 µm).

M.2.3 Probability of Finding Large MVDs

Figure M-3 illustrates the statistics for MVDs in stratiform clouds. There is a marked preference for MVDs close to 15 µm. That is, stratiform clouds with an MVD of about 15 µm appear to be the most stable. They are more common, can contain larger maximum LWCs, and can extend over far greater distances than clouds (or portions thereof) with larger MVDs. The larger the MVD, the less likely it is to occur, the less LWC it can contain, and the shorter the distance over which it can persist. The fact that about two thirds of all random encounters contain MVDs smaller than 15 µm shows that a large amount of data will be lost if the 14 CFR parts 25 and 29 Appendix C cutoff at 15 µm is used as a lower limit for evaluating data in natural icing test flights.

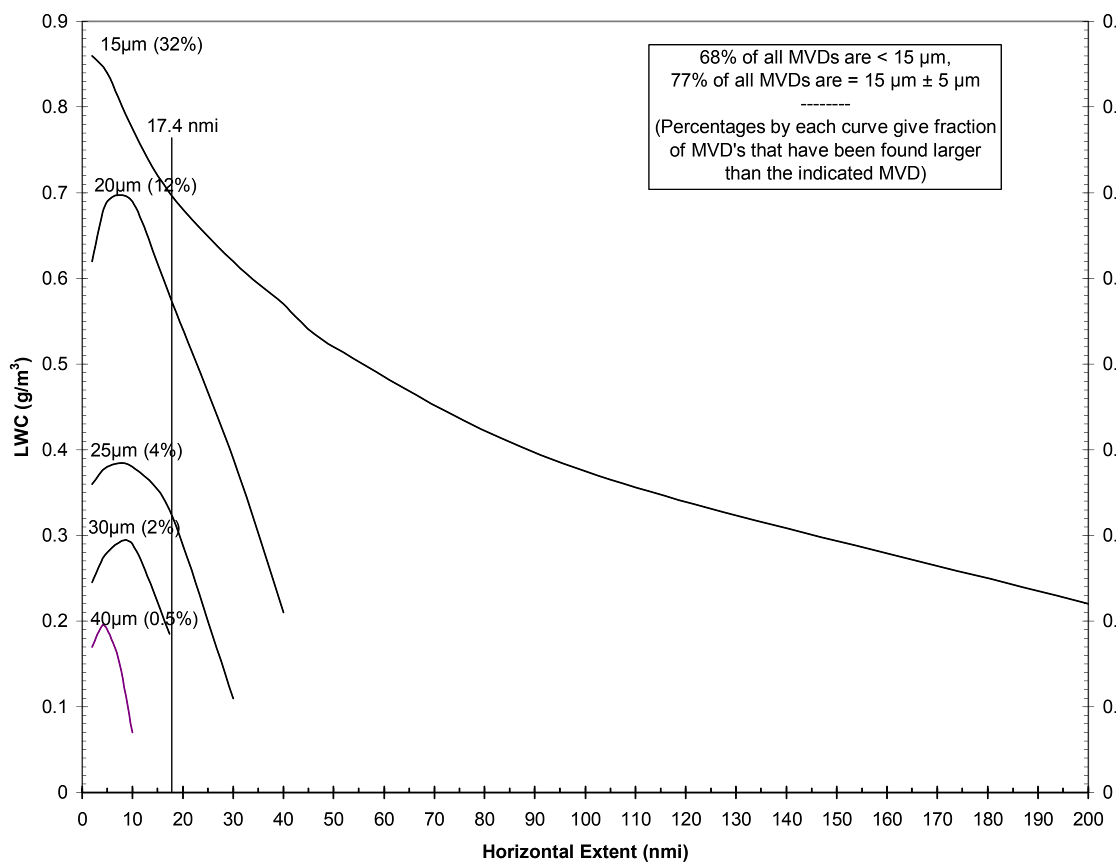


Figure M-3. Natural cloud horizontal extent limits and 99 percent LWC limits for selected, sustained cloud drop MVDs in stratiform clouds at ambient temperatures of 32° F to 14° F.

If large MVDs are still of interest for test flight purposes, the statistics suggest the following strategy.

Look for:

- Maritime air masses (e.g., Pacific coast of North America or the North Atlantic Ocean east of the Canadian maritime provinces)
- Flight altitude temperatures warmer than about –17° C
- Altitudes from 7000 to 14,000 Ft ASL
- Convective clouds (more suitable than layer clouds)

Expect to find:

- Horizontal extents (of large-MVD conditions) less than 10 nmi

- MVDs in the normal range of 10-20 μm most of the time

M.3 Experience

M.3.1 Continuous Maximum Conditions

Continuous maximum icing conditions of 14 CFR parts 25 and 29 Appendix C are usually found in stratiform clouds. Stratiform cloud decks with depths greater than 1000 ft are usually needed to get LWCs that are worthwhile for icing flight tests. Layer clouds composed of water droplets are seldom found with layer depths greater than about 6000 ft. In any case, the LWC generally increases with height in the cloud, so the larger LWCs will usually be found in the upper quarter of the layer.

In the United States, wintertime stratus clouds can often be found in the Great Lakes area. But other areas are suitable too, depending on the weather situation. The commercial or public weather maps on television or on the Internet [M3, M4] can be helpful here.

M.3.2 Intermittent Maximum Conditions

Intermittent maximum icing conditions of 14 CFR parts 25 and 29 Appendix C are typically found in cumuliform clouds. These icing conditions usually occur during vigorous convective activity that is scarce when the freezing level is low. Normally one has to look for springtime or summer weather where the freezing level is above 5000 ft to 10,000 ft AGL. A strategy that cloud physics researchers use is to penetrate the tops of isolated "feeder" cells or growing cumulus towers on the periphery of existing or growing, isolated thunderstorms. This provides relatively large LWCs without having to perform risky penetrations of the main thunderstorm core.

M.3.3 Glaciated Conditions

Glaciated clouds are not included in 14 CFR parts 25 and 29 Appendix C. Little or no icing is expected in glaciated (snow or ice crystal) clouds. The presence of snow at ground level in wintertime (non-thunderstorm) conditions is a good indication that the clouds above the 0° C level are glaciated and have little or no potential for icing an airframe.

Glaciated clouds in any season are recognizable by their lack of texture from both the inside and outside. From the outside their appearance has been likened to "cotton candy." The inside of most widespread, deep, stratiform-like glaciated conditions is very tenuous—it may look uniformly gray in all directions outside the aircraft but no cloud puffs will be seen nor any visible cloud passing by the wings. Snow may be present but unnoticeable unless illuminated by the landing lights or wingtip strobe lights. From underneath the cloud, a dull, featureless overcast will be seen.

Water droplet clouds are typically lumpy, resembling a cauliflower on the outside, especially on the sides and top. These clouds are denser, and puffs or cloudy parcels can be seen passing by the wing, sometimes partially or completely obscuring the wingtip.

M.3.4 Mixed-Phase Conditions

Mixed-phase icing conditions are not specifically included in 14 CFR parts 25 and 29 Appendix C. Mixed-phase icing conditions consist of ice crystals interspersed with liquid droplets. They may be expected in approximately 40 percent of continuous and intermittent maximum icing conditions. Care must be taken to account for these ice crystals when determining the liquid and total water content of clouds. To differentiate between water droplets and ice crystals requires special instrumentation such as a total water content probe or an instrument capable of discriminating between spherical water droplets and crystalline frozen water such as the PMS-2D-C probe. This discrimination is very time consuming and requires detailed investigation including differentiation between LWC and frozen water content to determine total water content.

M.3.5 Large Drop Conditions.

Although there are presently no requirements for IPS design and approval in large droplet icing conditions (which may be referred to as supercooled large droplet (SLD) conditions), they are discussed below for completeness. Large drop conditions include freezing drizzle and freezing rain.

Freezing drizzle (FZDZ) contains droplets from 50 µm up to 500 µm in diameter, but the conditions causing substantial numbers of these large drops to form are not well understood. Freezing drizzle aloft is presently difficult to predict. Thin layers of it have been observed at altitudes as high as 17,000 feet at temperatures as low as –17 °C. It occurs occasionally in and/or below stratiform clouds. Freezing drizzle can occur as a diffuse supercooled mist aloft in some northerly maritime areas such as coastal Alaska and Newfoundland [M5].

Freezing rain (FZRA), also known as ice storms, occur when snow falls through a warmer-than-freezing layer of air where the snowflakes melt into raindrops and fall to the ground through an underlying layer of sub-freezing air in contact with the ground. Aircraft (like trees, power lines, roads, and other objects) can become coated with a hard layer of clear ice. Freezing rain will affect aircraft during approach, landing, taxiing, takeoff, and transiting in the lowest few thousands feet above ground level. In the United States, freezing rain is most common east of the Rocky Mountains. It is usually easy to forecast and its expected location will be included in the daily weather forecasts.

M.4 Using Forecasts of Icing Conditions

Icing forecasts have been traditionally imprecise, due mainly to the ongoing difficulty of knowing when, whether, and where a given cloud interval above the freezing level will be liquid or glaciated. Forecasts typically read something like "icing in cloud and in precipitation above the freezing level." This language allows for the fact that, in the absence of recent pilot reports or other clues, clouds above the freezing level may be liquid in some places and therefore capable of icing an aircraft.

Icing forecasts are improving, at least in narrowing the vertical and horizontal boundaries of existing and expected icing-prone cloudiness. New, experimental, or operational graphical presentations of icing conditions are available on the Internet at http://cdm.aviationweather.noaa.gov/cip, *adds.aviation.noaa.gov*, and *http://www.dispatcher.org/brief/adfbrief.htnl*, (as of this writing) [M3, M4, M6]. These can be helpful by providing a quick and easy way to assess current icing conditions.

M.5 Professional Guidance

Certified consulting meteorologists and forecasting services for hire may be found in a professional directory maintained by the American Meteorological Society [M6]. Some of those listed will be knowledgeable in aircraft icing.

The Society of Automotive Engineers (SAE) has an active Aircraft Icing Technology committee (AC-9C) of icing practitioners which produces helpful, icing-related SAE publications [M7].

The FAA publishes an Advisory Circular listing Designated Engineering Representatives (DERs) who are available for consulting work [M8]. Some of these are experienced in aircraft icing applications.

M.6 References

M1. "**Icing Design Envelopes (14 CFR-25, 29, Appendix C) Converted to a Distance-Based Format,**" Richard K. Jeck, FAA Technical Report DOT/FAA/AR-00/30 (2000), FAA Technical Center, Atlantic City, NJ 08405.

M2. "**A New Database of Supercooled Cloud Variables for Altitudes up to 10,000 Feet AGL and the Implications for Low Altitude Aircraft Icing,**" Richard K. Jeck, DOT/FAA/CT-83/21 (1983), FAA Technical Center, Atlantic City, NJ 08405.

M3. Aviation Weather Center: http://www.awc-kc.noaa.gov

M4. National Weather Service: http://weather.noaa.gov

M5. **An Inferred Climatology of In-Flight Icing and SLD for North America**, Bernstein, B.C., Proceedings of the 10th American Meteorological Society Aviation Range and Aerospace Meteorology Conference, Portland, Oregon, May, 2002, pp. J21-J24.

M6. American Meteorological Society, 45 Beacon Street, Boston, MA 02108-3693. Tel: 617-227-2425. Internet: http://www.ametsoc.org.

M7. Society of Automotive Engineers: http://forums.sae.org/access/dispatch.cgi

M8. "**Designated Engineering Representatives Consultant Directory,**" Advisory Circular No. 183.29-1HH (2000), Federal Aviation Administration, 800 Independence Ave. SW, Washington, DC 20591.